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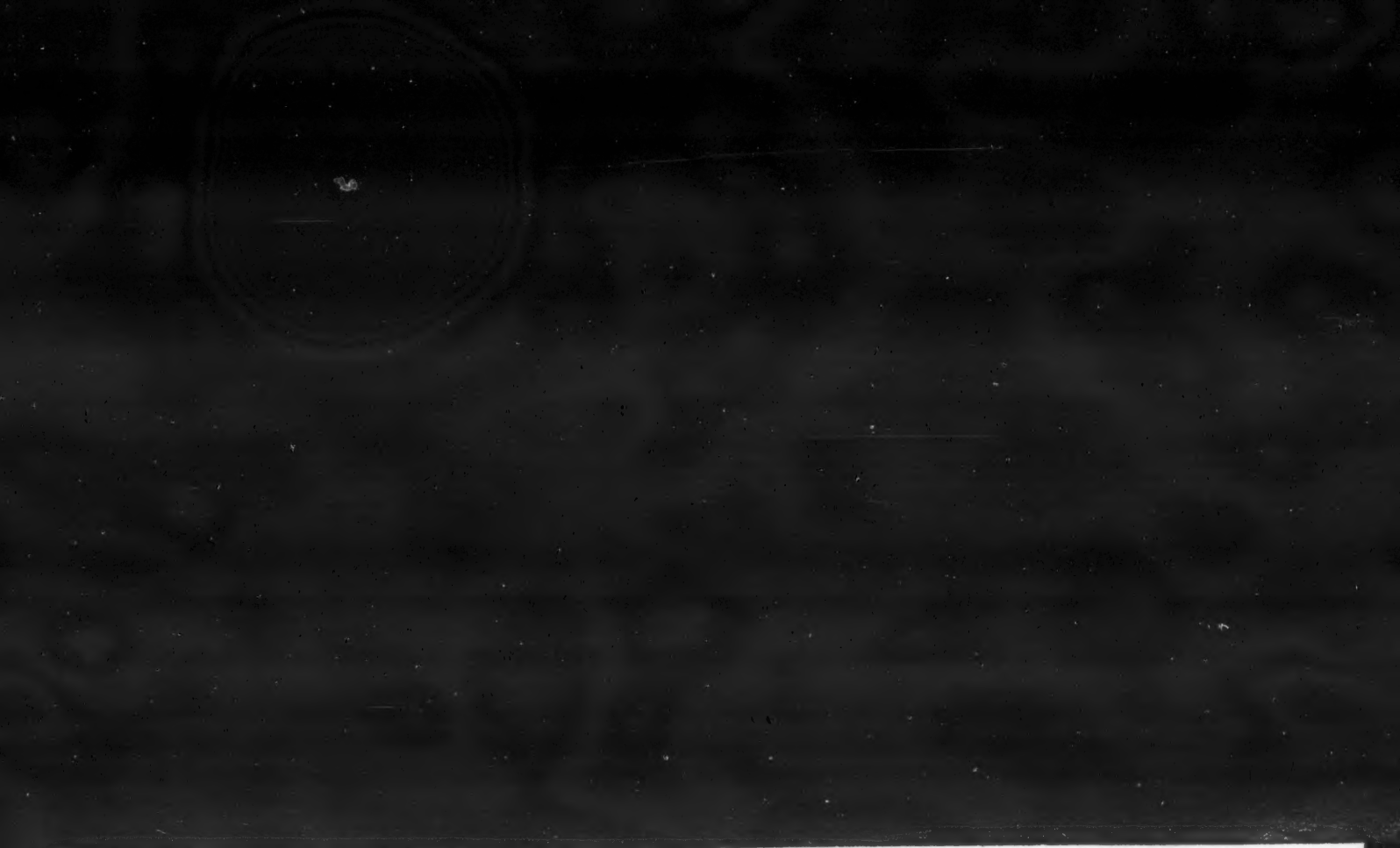
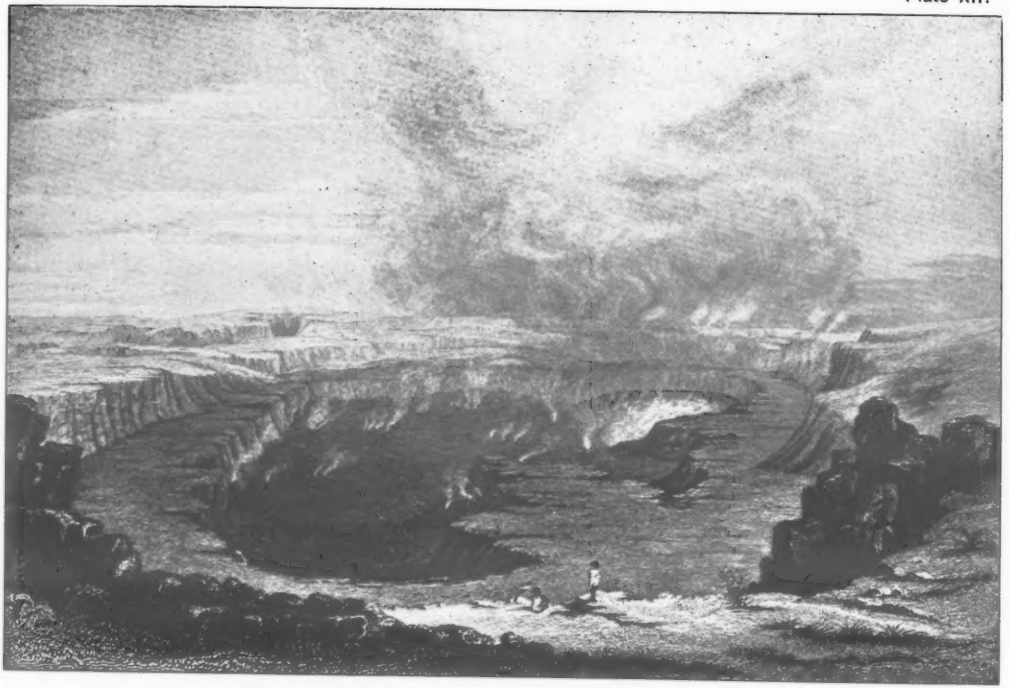
DANA'S WORKS.

IVISON, BLAKEMAN, TAYLOR & Co., New York.—**Manual of Geology,** by J. D DANA. **Third Edition,** 1880. 912 pp. 8vo. $5.00.—**Text-book of Geology** by the same. **4th ed.** 1883. 412 pp. 12mo. $2.00.—**The Geological Story Briefly Told,** by the same. 264 pp. 12mo. 1875.

J. WILEY & SONS, New York.—**Treatise on Mineralogy,** by J. D. DANA. 5th edit. xlviii and 828 pp. 8vo., 1868. $10.00. The 5th "subedition" was issued by Wiley & Son in April, 1874. (Each "subedition" (or issue from the stereotype plates), contains corrections of all errors discovered in the work up to the date of its publication). Also, Appendix I, by G. J. Brush, 1872. Appendix II, by E. S. Dana, 1875.—**Manual of Mineralogy & Lithology,** by J. D. DANA. 3d edition. 474 pp. 12mo., 1878.—**Text-book of Mineralogy,** by E. S. DANA. Revised edition. 512 pp. 8vo., 1883.—**Text-book of Elementary Mechanics,** by E. S. DANA. 300 pp. with numerous cuts, 12mo., 1881.—**Manual of Determinative Mineralogy,** with an Introduction on Blow-pipe Analysis, by GEORGE J. BRUSH. 8vo., 2d ed. 1877. Third Appendix to Dana's Mineralogy, by E. S. DANA. 136 pp. 8vo. 1882.

DODD & MEAD, New York.—**Corals and Coral Islands,** by J. D. DANA. 398 pp. 8vo. with 100 Illustrations and several maps. 2d ed., 1874.





CRATER OF KILAUEA. J. Drayton, U. S. Expl. Exped., 1840.

THE

AMERICAN JOURNAL OF SCIENCE.

[THIRD SERIES.]

ART. XLIV.—*History of the Changes in the Mt. Loa Craters, on Hawaii;* by JAMES D. DANA. With Plate XII.

THE instructive papers of Messrs. Emerson, Van Slyke and Dodge (p. 87) are a good beginning for a future history of the Hawaiian volcanoes. The earlier history, for sixty-five years back, has a source of material in three scientific reports: that of Captain C. E. Dutton (1883),* the memoir of Mr. Wm. T. Brigham, who visited the region in 1864 and 1865,† and the report of the writer,‡ after an examination in 1840, each of which may be assumed to give the facts as they were observed, whatever the value of the explanations offered. In connection with these should be mentioned the descriptions and illustrations in the Narrative of the Exploring Expedition by Captain Wilkes.§ There are also accounts from various other sources which, although in many cases overdrawn, contain information of

* In the Fourth Annual Report of the Director of the U. S. Geol. Survey, 1882–'83, 140 pp. roy. 8vo, with maps and plates of Kilauea, the Mt. Loa crater, etc.

† Notes on the volcanoes of the Hawaiian Islands, with a history of their various eruptions, by Wm. T. Brigham, A.M., Mem. Boston Soc. Nat. Hist., vol. i, Part ii. 126 pp. 4to, with four plates (including a new map of Kilauea) and several woodcuts. 1868. Mr. Brigham's map is reproduced in Captain Dutton's Report, but without explanation or remark.

‡ Report Geol. Wilkes Expl. Exped., 756 pp., 4to, with folio atlas, 1849.

§ Narrative of the Expl. Exped., by Charles Wilkes, U. S. N., Commander of the Expedition, 1838–1842. 5 vols. roy. 8vo, with an atlas. 1845. The account of the volcanoes of Hawaii is in vol. iv. Captain Wilkes required his officers to keep journals, and used them as a source for part of the material for his Narrative.

much importance. In my Geological Report I endeavored to bring the history in a brief way down to 1849, the time of its publication. Mr. Brigham reviewed the same to the date of his last examination in 1865.

Captain Dutton gives his own observations in 1882, and his conclusions, with a few citations from other accounts; but the condition of the crater at the time of the visit was not favorable for an appreciation of the phases of the volcano or for an understanding of all its phenomena; and he is led to doubt much that was well reported before him, very much more than appears, in the light of the facts presented beyond, to be reasonable.

The conclusions he gathers from the accounts, as stated on pp. 117, 118 of his Report, are the following:

"At the present time [1882] the liquid lava columns stand about 435 feet higher than they did forty years ago. No record has ever been kept of the progressive action by which these changes have been brought about. Nothing remains to show the successive steps in the accretion of lavas which gradually filled up the interior pit. The only guides we have are the fragmentary accounts of numberless visitors describing the condition of Kilauea from time to time. These are all so incoherent, and so grossly wanting in precision, that it is impossible to frame a connected account of the process.

"There are, however, a few general features of the process which appear, and these may be briefly summarized. All accounts go to show that the height of the liquid column oscillates in an irregular manner; and while most of these oscillations are small, usually not exceeding ten to fifteen feet, yet in exceptional cases they are very much greater. Whenever the liquid column rises there is a tendency to overflow the margin of the pool which surrounds it, and this frequently happens. The quantities of lava thus outflowing and spreading out over a considerable area vary extremely, being sufficient sometimes to cover no more than a few acres to the thickness of a very few feet, while on rare occasions a square mile or two may be overflowed with a considerable body. The duration of these overflows is also extremely variable. Sometimes it is a single belch or surge lasting but a few minutes. It is quite common for the lava to run in this way for a whole day, and in large outflows it may run for two or three weeks without interruption. Sooner or later the liquid column sinks and the overflow ceases. The eruptions are not by any means confined to the lakes, but break out at unexpected places. One of the most favored spots for this action is the former focus of the Old South Lake, which for several years has been completely frozen over. The cooling lava invariably takes the form of pahoehoe."

The above meagre summary, which Captain Dutton's facts, and his knowledge of the descriptions of earlier "visitors,"

have enabled him to present, contains little, it is true, that is important to the science of volcanoes. After a careful sifting of all the earlier accounts with reference to statements bearing on the progressive changes in the craters of Kilauea and Mt. Loa, I have found that very much more is taught. What, and of what significance, the following pages aim to show.

I. KILAUEA.

Besides the publications already mentioned, the following, relating to Kilauea prior to 1841, are cited from beyond, and referred to by means of the Roman numerals here prefixed. I add some descriptive and critical notes that the facts reported may be received with proper discrimination.

I. *a.* Journal of a Tour around Hawaii [in August, 1823] by a Deputation from the Mission of the Sandwich Islands. 264 pp. 8vo, with six plates. Boston, 1825 (Crocker & Brewster). "Drawn up by the Rev. Wm. Ellis," of England, one of the party, "from minutes kept by himself and by his associates on the tour, who subsequently gave it their approbation." Contains, facing p. 136, a night-view of "the south end of Kilauea," from a sketch taken by Mr. Ellis, looking southwestward,* engraved by S. S. Jocelyn, of New Haven, Ct. See also Missionary Herald, xxii, 25, 1826. *b.* London edition, "with large additions," 1826, under the title, "Narrative of a Tour through Hawaii;" 3d edit., March, 1827, 480 pp. 8vo. Contains, facing p. 226, a day-view of the "southwest end" of Kilauea, engraved, from the same sketch, in England; but a large cone stands where was the foot of a lava-stream descending the west wall; two cones are omitted; the active cones give out steam quietly. See p. 438.

II. Polynesian Researches, by Rev. Wm. Ellis, 2d edition, 4 vols. 12mo, London, 1831. The first edition, 2 vols. 8vo, published in 1829, contains nothing about Hawaii. In preparing for a second edition, the Narrative (I *b*) was added (as the fourth vol.); and, for a frontispiece to this volume, a new engraving of Kilauea (from a painting—a night-view) was introduced, having the subscript, "The volcano of Kilauea in Hawaii. Sketched by W. Ellis. Painted by E. Howard, Jr. . . . London, 1831." A copy of this plate, with the subscript, "Blowing Cones. Reproduced from Ellis' Polynesian Research, 1823," is contained in the Report of Captain Dutton. An outline copy is introduced beyond, on p. 441. The plate differs widely from those of 1825 and 1826;

* Leaving the north end of the crater, says the "Journal," p. 145 (and "Narrative," p. 247) "we passed along to the east side, where Mr. Ellis took a sketch of the southwest end of the crater." And then, in the next sentence, "As we travelled from this spot we unexpectedly came to another crater" nearly half as large as the former. The native name of it is Kirauea-iti [Kilauea-Iki, as now written]; "it is separated from the large crater by an isthmus nearly 100 yards wide." The position from which the view was taken was hence north of Byron's hut (p. 440), either on the isthmus referred to or farther north on the bluff adjacent.

and since the text (Polyn. Res., vol. iv, p. 266) gives the same statement as the Narrative as to where the sketch was taken, the artist's fancy is evidently the chief source of the differences. The cones are fewer, but they are as active; and one, placed out in the front, is a grand high shooter, far outdoing any of those on the other plates. Further, the features of the black ledge and the wall above are changed on both sides of the pit, and the Great South Lake is put in a *southeast* recess instead of to the southwest. Mr. Ellis was a second time at Kilauea, but this was before 1826. He then found the crater much more quiet, and "the fires in the south and west burning but feebly."

III. Journal of a voyage to the Pacific Ocean and residence at the Sandwich Islands, 1822–1825; by Rev. C. S. STEWART. 8vo. New York, 1828. Contains an account of a visit to Kilauea, made on July 2, 1825. Am. J. Sci., xi, 363, 1826.

IV. Visit to the South Seas, by C. S. STEWART. 2 vols. 12mo. New York, 1831. In vol. ii, an account of Kilauea after a visit Oct. 9, 1829, not overdrawn like that in the preceding work. Am. J. Sci., xx, 229, 1831.

V. Voyage of H. M. S. Blonde to the Sandwich Islands in the years 1824, 1825, by Right Hon. Lord BYRON, Commander. 260 pp. 4to, with plates. London, 1826. Contains an account of a visit to Kilauea on June 28, 29 (29, 30, American time), illustrated by a folded plate presenting a view of the volcano, by R. DAMPIER, in which the many cones give out vapors quietly, and a map of the crater by Lieut. MALDEN, R. N. (see p. 441 beyond).

VI. Letters of Rev. JOSEPH GOODRICH: *a*, Am. J. Sci., xi, 2, 1826, letter of April 20, 1825; *b*, ibid., xvi, 345, 1829, letter of Oct. 25, 1828; *c*, ibid., xvi, 346, letter of June 12, 1828; *d*, ibid., xxv, 199, 1834, letter of Nov. 17, 1832.

VII. Letter of Rev. A. BISHOP, Missionary Herald, xxiii, 53, 1827, after a visit to Kilauea, Jan. 3, 1826.

VIII. Note of Rev. L. CHAMBERLAIN, after a visit to Kilauea with J. Goodrich, Dec., 1824, Missionary Herald, xxii, 42, 1826; also in Ellis's Pol. Res., iv. 253, and Phil. Mag., Sept., 1826.

IX. *a*. Memoir of DAVID DOUGLAS, by Dr. W. J. Hooker, with portrait, letters and Journal, Companion of the Bot. Mag., ii, 79–182, 1836; the part on Hawaii, pp. 158–177. The visit to Kilauea was on Jan. 23–25, 1834, and to top of Mauna Loa, on Jan. 29; the account of the latter in his Journal, p. 175, and that in a letter to Dr. Hooker, p. 158.—*b*. Letter to Capt. Sabine, dated Oahu, May 3, 1834, partly from his Journal, but with additional material on his barometric, hygrometric, thermometric and hypsometric observations, Journal Royal Geogr. Soc., iv, 333–334, 1834. —*c*. Extracts from the Journal of Mr. Douglas, Mag. Zool. and Bot., i, 582, 1837, and including the letter to Dr. Hooker which describes Mt. Loa.

Mr. Douglas spent a dozen years in travels over N. America (Oregon, California, Hudson's Bay region, etc.) as an exploring

naturalist, and twice visited the Sandwich Islands, making collections and observations in botany, zoology, etc., part of the time under the auspices of the Horticultural Society of London. His instruments included a barometer, chronometers, a reflecting circle, large dipping needle, etc. While on an excursion over Hawaii in July, 1834 (then 35 years old), he fell into a pit made to entrap wild cattle and was gored to death.

X. Account, by E. G. KELLEY, of observations made at Kilauea by Captains CHASE and PARKER, on the 8th of May, 1838, and published, after submission to Capts. C. and P., in this Journal, xl, 117, 1841, with a map of the crater (see p. 448).

XI. Notes of Count Strzlecki, after a visit to Kilauea in 1838, in his "New South Wales and Van Diemens Land," 8vo, London, 1845, and cited in quotation marks from, he says, his "manuscript notes." Also a note in the Hawaiian Spectator, i, 436, but the facts differently stated—see note, p. 449.

XII. Account, by Captain JOHN SHEPHERD, R. N., after a visit, Sept. 16, 1839, contained in the London Athenæum of Nov. 14, 1840, p. 909.

XIII. Account, by Rev. TITUS COAN, dated September, 1840, Missionary Herald, xxxvii, 283.

XIV. Rev. H. Bingham's Residence of thirty-one years in the Sandwich Islands, 1847.

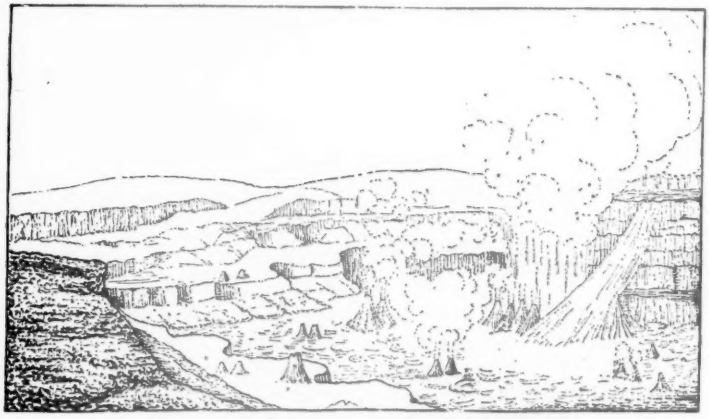
1. KILAUEA FROM JAN. 1823 TO JAN. 1841.

For convenient reference in describing the varying phases of the volcano, I introduce (see Plate XII) a view of the crater of Kilauea from its north side, as it appeared in December, 1840,* when it had, as a consequence of the eruption about six months before, a lower pit, and a "black ledge," besides the great southern lake of lavas, Halema'uma'u, all well defined. The artist of the expedition, Mr. J. Drayton, has, with the aid of his camera lucida, brought out well the features of the scene. The more distant wall is about 14,000 feet from the near side, and this is not far from the idea the view conveys, quite as nearly so as it appears to be in the actual scene. But one or two points of geological importance have been overlooked which should be mentioned to forestall wrong inferences; one is, the omission of the stratification of the wall, which is a marked feature; and another is the giving a slight concavity to the floor of the crater in the northern or near part, which was not a fact. The small jets of vapor over the bottom arise, with a single exception, from fissures or cavern-like openings; and such escapes of vapor are greatly multiplied by a rain. The exception was that of a lava-lake, about 200 feet in diameter, named Judd's Lake in the "Narrative," which was the

* Copied from the plate facing page 125, in the 4th volume of Wilkes's Narrative.

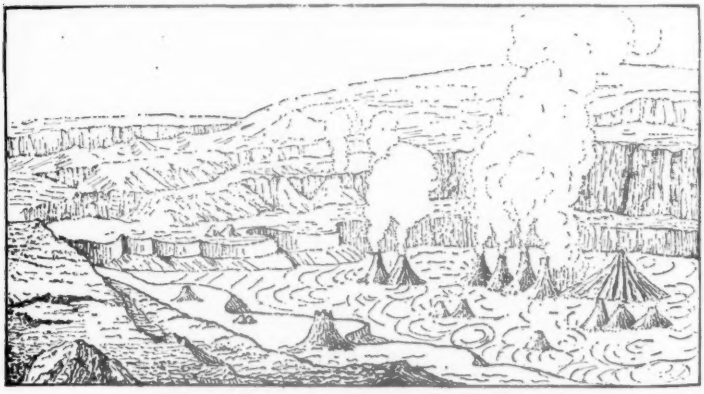
larger of two small lakes that were active in November, at the time of my visit.

1. BEFORE THE ERUPTION OF 1823.—The condition of Kilauea prior to the eruption of 1823 is known only from statements in the "Journal of the Deputation of the Mission" (I*a*), or the "Narrative" (I*b*), and in a letter of Rev. Joseph



1. "The south end of Kilauea." Sketched by W. Ellis.

Goodrich (VI*a*), both made after the visit of August 23, and based on evidence, seen by each of the party, that a high-level



2. "The southwest end of Kilauea." W. Ellis, del.

mark existed in a "black ledge," as it was then called, running like a terrace-plain around the interior, some hundreds of feet above the bottom. "It was evident," says the Journal, "that

the crater had been recently filled with lavas up to the black ledge;" and Mr. Goodrich remarks that "the black ledge was made by the crater's being filled to that level" (VI*a*). This conclusion was evidently derived from the features of the ledge; for this was the first visit of foreigners. Still they may have had a hint from the islanders, one of whom in 1826, told the Rev. Mr. Bishop that "after rising a little higher the lava would discharge itself toward the sea as formerly by an underground way." I introduce here (fig. 1) an outline copy of the plate in the Journal (I*a*), and also (fig. 2) of that in the Narrative (I*b*), both reduced. They corroborate one another in all the main points, though having differences due either to corrections in England, or to changes suggested by Mr. Ellis. The black ledge borders the lower pit around, as in 1840, but is very narrow.

The eruption probably took place between the preceding months of March and June. At Ponahohoa in Kapapala, they saw (I*a*, p. 117) a large sunken area, 50 feet deep, fissured in all directions, besides steaming chasms, and ejections of fresh lava, which they were told by the natives of the place were made by Pele two moons before; and by natives of Kearakomo, five moons before (p. 151). It is added: "Perhaps the body of the lava that had filled Kilauea up to the black ledge" "had been drawn off by this subterranean channel."*

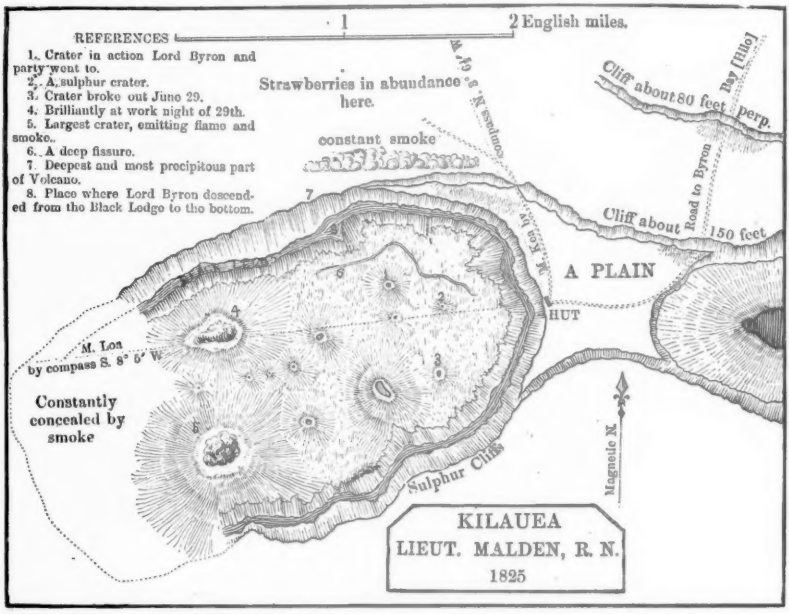
2. After the Eruption of 1823. *a. Size of the Crater.*—The discharge, wherever it took place, was followed in the crater by a down plunge of part of the floor, giving Kilauea its lower pit and "black ledge." The depth of the lower pit was estimated by the Mission party at 300 or 400 feet; and the total depth of the crater, 700 to 800, making the former nearly or quite half the latter. Mr. Goodrich, who was at the crater with the party, and three times afterward before April, 1825, estimated the whole depth at over 1000 feet, and that of the lower pit at 500 (VI*a*), the latter again half the former.

Lieut. Malden, R. N., of the Blonde (V, p. 184) made a map of the crater (of which the following is a copy reduced one-third),† and measured the height of the high northwest wall above the black ledge. He states, in a note to Lord Byron's work, that he obtained by triangulation, 8209 feet for the distance across from the "Hut," the place of encampment, to the

* It is a favoring fact that Mr. David Douglas in January, 1834, had information from the natives that in 1822 there was a great discharge in the Kapapala direction (IX*b*, p. 170). The same region was fissured and had its small ejections of lava at the eruption of Kilauea in 1868, and probably a large outflow off the coast.

† This copy has the lettering of the original, excepting the title, which is "A plan of the Volcano Peli, in the island of Owhyhee, by Lieut. Malden, R.N., 1825;" also the east half of Kilauea Iki is omitted.

highest part of the western wall, a point numbered 7 on his map, which is, in all probability, Kamohoalii of Mr. Dodge's map (Plate II of this volume), and 5° 55′ for the angle subtended by the wall between its summit and the black ledge; and that he thus made the height of the wall, 932 feet. There is here a slip, for the data give 851 in place of 932. The most recent survey makes that distance 8750 feet, using which

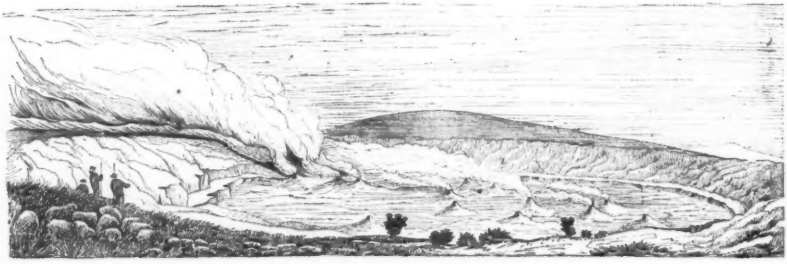

REFERENCES
1. Crater in action Lord Byron and party went to.
2. A sulphur crater.
3. Crater broke out June 29.
4. Brilliantly at work night of 29th.
5. Largest crater, emitting flame and smoke.
6. A deep fissure.
7. Deepest and most precipitous part of Volcano.
8. Place where Lord Byron descended from the Black Ledge to the bottom.
1 2 English miles.
Strawberries in abundance here.
constant smoke
Cliff about 80 feet perp.
Cliff about 150 feet
Road to Byron
A PLAIN
HUT
M. Loa by compass S. 8° 0′ W.
Constantly concealed by smoke
Sulphur Cliffs
Magnetic N.
KILAUEA
LIEUT. MALDEN, R. N.
1825

number in the calculation we get 907 for the height of the wall. It is therefore probable that 900 feet is not far from right.

Lieut. Malden *estimated* the depth of the lower pit at 400 feet (and Dampier's sketch beyond accords with this); but he saw it only from above (illness preventing his descent), and more than two years after the eruption. The observers of August, 1823, and Rev. Mr. Stewart in 1825, made it nearly or quite half of the total depth (giving for the total 1700 or 1800), and this is assumed by Mr. Goodrich in his later letters.

All accounts and pictures, together with Lieut. Malden's map, make the black ledge narrow. The plates from Ellis's sketch in the "Journal" and "Narrative" (p. 438) make the eastern side of it the broader; but the part shown is really the south-

eastern, toward the sulphur banks; and there Rev. E. Loomis, in June, 1824, found it by measurement to be "nearly fifteen rods" wide.* Lord Byron, on his descent into the pit, went from the northeast to the northwest side, and says: the width (referring probably to the north side) varies from four or five feet to upwards of twenty. The annexed sketch,

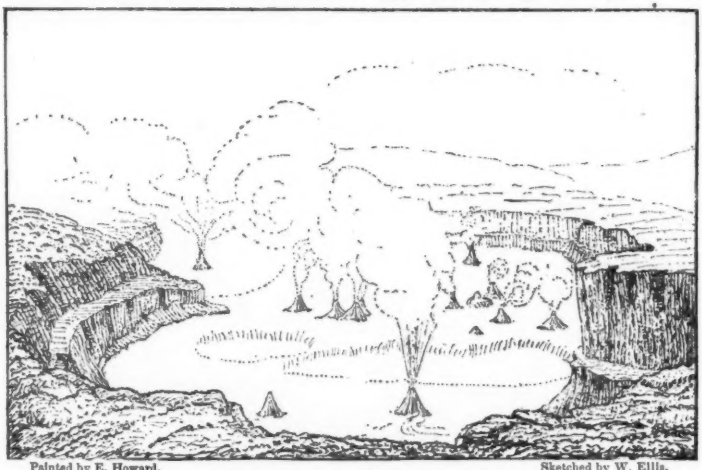


4. Kilauea. Drawn by R. Dampier.

which is a copy (reduced one-third) of the plate by R. Dampier, making the frontispiece to Lord Byron's "Voyage" (V), has the ledge very narrow.† It is not quite certain what part of the crater the view represents. Mts. Loa and Kea are in the

* Memoir of Wm. T. Brigham, p. 407.

† The plate in Ellis's Polynesian Researches makes the breadth about the same on the two sides, as the following outline copy (reduced a sixth) shows; but, as



Painted by E. Howard. Sketched by W. Ellis.

5. The Volcano of Kilauea, in Hawaii.

has been explained (p. 436) it has little value as to details. In the relative depths, however, of the lower pit and upper portion it agrees better with the several descriptions than the other plates.

distance and the chief seat of fires is to the left, and by comparing with Lieut. Malden's map and Drayton's plates the position required for such a view can be ascertained. Rev. C. S. Stewart describes the ledge as in some places many rods, in others a few feet wide. Mr. Goodrich (VI*a*), after having measured the whole length of one side, remarks that "it is like a stair, although it is half a mile wide some part of the way"—which part he does not say.

On the 22d of December, 1824, Mr. Goodrich (VI*a*), with Mr. Chamberlain (VIII), measured the circumference of Kilauea at the top *with a line*, and made it 7½ miles; which is the length it has on Mr. Dodge's map, the scale of which is 500 feet to the inch. They measured the crater also on the black ledge, going half way around it and estimating for the rest, and obtained, as the result, 5½ miles for the circumference of the lower pit, which I find to be probably nearly right.

b. Condition of the crater after the eruption.—The "Journal" (I*a*) says, on page 131, "the southwest and northern parts of the crater were one vast flood of liquid fire, in a state of terrific ebullition." "Fifty-one craters, of varied form and size, rose like so many conical islands, from the surface of the burning lake. Twenty-two constantly emitted columns of gray smoke or pyramids of brilliant flame [lava-jets?], and many of them at the same time vomited from their ignited mouths streams of florid lava which rolled in blazing torrents down their black, indented sides into the boiling mass below." In a night scene, p. 136, "the agitated mass of liquid lava, like a flood of metal, raged with tumultuous whirl," and "at frequent intervals shot up, with loudest detonations, spherical masses of fusing lava or bright ignited stones."*

Descending to the black ledge (Journal, p. 144) they "entered several small craters," "bearing marks of very recent fusion," "and many which from the top had appeared insignificant as mole-hills" proved to be "12 or 20 feet high." They also collected the "hair of Pele," and afterwards found it seven miles south of the crater, "where it had been wafted by the winds."

* The plate in the "Journal" of the "south end" represents "one" continuous area of lavas in "tumultuous whirl," in accord with the text, and that in the "Narrative" is similar, but with more extravagant whirls, for they are hundreds of feet in diameter, and even the black ledge is covered by them. The engraver has apparently tried to conform to the description. In the plate of the Polynesian Researches, the liquid surface is confined to the great South Lake, and a separate large area (or two of them), and nothing of the "tumultuous whirl" is represented, although the expression remains in the text (p. 245). It seems probable from the description that the party saw only "one" great lake, that of the South end, and that great overflowings sent streams far northward. The height of the throw of stones (see plates) is evidently an exaggeration, as it is inconsistent with the condition of "ebullition" at the time, and with all that has been said of Kilauea since. The text says "shot up," but does not say how high.

Mr. Ellis argues from the "conical islands" (I*b*, p. 226, and II, iv, p. 237) that the boiling caldron of melted lava "was comparatively shallow," implying that the cones stood on the solid bottom of the lake. He also noticed that the walls of Kilauea were "composed of different strata of ancient lava."

On page 144, the Journal (I*a*), after describing long, covered, tunnel-like chambers occupying the emptied interiors of lava streams, the upper surface rippled, the roof "hung with red and brown stalactitic lava," and "the bottom one continued glassy stream," says that they followed one such covered way "to the edge of the precipice that bounds the great crater, and looked over the fearful steep down which the fiery cascade had rushed, the fall "several hundred feet." The plate in the "Journal" (p. 438) represents rudely such a stream descending the *west* wall (like that of 1832, on the opposite side of the crater); but it is strangely (perhaps because badly drawn) omitted from the plate in the "Narrative."

Mr. Goodrich's letter on April, 1825 (VI*a*), does not distinguish the events of his first four visits. He observes that in February, 1825, he counted twelve places where the lava was red hot, and three or four where it was "spouting up lava 30 or 40 feet"; and mentions the escape of vapors in many places, making "a tremendous roaring." On December 22, 1824, a crater opened in the bottom where the lavas boiled like a fountain, with jets 40 to 50 feet high, and flowed off 50 or 60 rods.

Lord Byron's "Voyage" states (p. 184) that on June 30th, 1825, "fifty cones of various height appeared below," at least "one-half of these in activity"; and Mr. R. Dampier's sketch represents such a scene. Lieut. Malden's map makes the cones fewer and very broad, unlike the descriptions; crater No. 5 (p. 440) is probably Halema'uma'u, for the distance from the hut is right for it, and if so the part "concealed by smoke" was of much less extent than was supposed by the party.

Rev. C. S. Stewart, who was with the party from the Blonde, makes the same statement (III) as to the number of "conical craters," and the position of the great seat of action in the southwest. He describes (p. 298) the black ledge as covered with tortuous streams of shining lava bearing "incontestible evidence of once having been the level of the fiery flood," and adds that "a subduction of lava" had "sunk the abyss many hundreds of feet to its present depth." A cone on the bottom, visited by the party, spoken of as "one of the largest," "whose laborious action" had attracted attention during the night (p. 304 and No. 1 on the map), was judged to be 150 feet high "a huge, irregularly shapen, inverted funnel of lava, covered with clefts and orifices, from which bodies of steam escaped with deafen-

ing explosions, while pale flames, ashes, stones and lava were propelled with equal force and noise from its ragged yawning mouth." The following night, crater No. 3 (Malden's map) became suddenly eruptive, and a lake of fire (No. 4?), perhaps two miles in circumference, opened in the more distant part.

Mr. Bishop, after a visit, Jan. 3, 1826, reported (VII) a similar condition of the crater; and also the filling up of the lower pit since August, 1823, of 400 feet—probably on the view that the original depth was 900 feet.

It will be observed that the above citations from Mr. Ellis and other early writers on Kilauea contain no mention of "blowing cones," except what is implied in the general descriptions. This is true of other later reports, including that of Captain Wilkes, who saw no cone in action. Further, it appears that the blowing described was done partly by the small cones, and partly by openings or oven-shaped places over the floor of the crater, as implied in the statement of Mr. Goodrich (p. 443), just as was true in 1886. They blow violently because they are small, or have relatively small apertures, so that the imprisoned vapors, on bursting the envelope of liquid or semi-liquid lava, go out with a rush and a roar. The only heights of ejections of lava mentioned are 30 to 40 and 50 feet; and the heights of cones 12, 20, and, for "one of the largest cones," 150 feet; which are common facts of later time down to the present.*

The close correspondence between the heights and character of ejections given in the earlier accounts, and those of recent years, is interesting as proving long-continued uniformity as to kind and quality of work even to the blowholes. The activity was however greater and more general than has been witnessed for many years. There are exaggerations, but they are mostly confined to the pictures, and to some of the general descriptions. The *estimates* made were usually below the truth, from honest caution.

Further, Mr. Ellis guards the reader, as has been shown, against the inference, from the island-like position of the cones in the region of liquid lavas, that they were floating-cones.†

* It is obvious that the high-shooting cone in the plate of Ellis's Polynesian Researches (II), blowing to a height of 700 or 800 feet (measuring it by the height of the upper wall), is the artist's fancy sketch, as suggested on page 436. It is wholly un-Kilauean and fundamentally out of place. The earlier plate from Mr. Ellis's sketch in the 'Journal' (I), also exaggerates, but only a third as much except over the South Lake.

† On page 111 of Captain Dutton's Report, the author presents the case differently, as follows.—"The earlier visitors to Kilauea whose accounts of it are now accessible speak of a phenomenon which did not exist at the time of my visit. I refer here to what has been termed 'blowing cones' within the lake. Ellis, in his account of Kilauea in 1823, described them as 'conical inverted funnels' rising to heights varying from twenty to forty, or even fifty feet above the surface

c. Progress in the filling of the lower pit.—As early as February, 1825, Mr. Goodrich stated, in view of the overflows he had observed, and the making of a "mound" over 60 feet high in six weeks, that the pit had begun to fill up (VI*a*); and in his letter of October 25, 1828, (VI*b*) he made the pit to have diminished in depth since August, 1823, by 300 or 400 feet. A year later, Oct. 25, 1829, Mr. Stewart (VI) described the lavas as still 200 feet below the level of the black ledge—which implies a filling of 400 feet, if the depth in 1823 was 600 feet, and of 600 if 800 feet deep. He states that although the crater was comparatively quiet, the bottom was crossed by a chain of lava-lakes, one of them a mile wide, throwing up masses of lava 15 to 20 feet; and that there were also six cones in action in the lower pit and one on the black ledge. Here again the height of the ejections mentioned is small. In October, 1830, the black ledge was still distinct (XIV, p. 387.)

3. BEFORE THE ERUPTION OF 1832.—Before the eruption of 1832, as Mr. Goodrich states, after a visit to Kilauea "about the 1st of September" of that year (VI*d*), "the crater had been filled up to the black ledge and about fifty feet above, about 900 feet in the whole since I first visited it, and it had now again sunk down to nearly the same depth as at first (in 1823), leaving as usual a boiling caldron at the south end." The precise time of the discharge and down-plunge is not stated. He adds, "The earthquake of January last had rent in twain the walls of the crater on the east side, from the top to the bottom, producing seams from a few inches to several yards in width, from which the region around was deluged with lava." "The chasms passed within a few yards of where Mr. Stewart, Lord Byron, myself and others had slept," "so that the very spot where I have lain quietly many times is entirely overrun with lava." (See map, p. 440). This outflow is stated by Mr. David Douglas (IX*b*) to have occurred in June, 1832. We may conclude, therefore, that the time of eruption was probably in January, but perhaps in June of 1832; certainly before September 1832, the time of Mr. Goodrich's visit.

4. AFTER THE ERUPTION.—*a. Size of the crater after the eruption.*—As to the new depth of the lower pit, we have first Mr.

of the lake, with openings at the top from which jets of vapor and sometimes spouts of lava were thrown out. As many as fifty were seen at one time within the great lava lake then existing, and most of them were simultaneously active. The same phenomenon was described in 1825 by parties from H. B. M. frigate Blonde. They were also observed by Wilkes in 1841, and have frequently been seen within the last ten or fifteen years by many other visitors. They appear to have been composed of solidified but very hot lava. None of them were permanent, but after a short period of activity they were either melted down, or shifted their positions. Ultimately, no doubt, they were remelted. That they shifted their positions is fully attested by many observers. Most probably they were masses of solidified lava floating like bergs in the lake."

Goodrich's statement above cited, "the same depth as at first," and the additional remark that the filling amounted to "about 900 feet"; which statement would make the depth of the lower pit after the eruption of 1832 nearly 900 feet, and of the crater from top to bottom 1750 feet. This estimate of the original depth accords with his view in 1825 that the upper and lower walls were of nearly equal height, and that Lieut. Malden's measurement was therefore good for both. There is no published account furnishing data for correcting this estimate.

By letter from Mr. W. D. Alexander, Surveyor General of the Hawaiian Islands, dated March 2, 1887, I learn that his father, Rev. Wm. C. Alexander (who arrived at the Sandwich Islands in 1832) visited the crater on the 12th of January, 1833, four months after Mr. Goodrich's visit, and in his private diary gives the depth of the crater as 2000 feet. This tends to confirm Mr. Goodrich's numbers, although only a rough estimate. He says nothing of any black ledge, except of that at the bottom of the 2,000 feet; and this leads to the inference that the ledge was quite narrow, as in 1823.

On the 22nd of January, 1834, Mr. David Douglas, of Scotland (XI), made careful barometric measurements of the crater, (all the details of which, with the calculation, are given in his letter to Captain Sabine, IX*b*). He obtained for the depth to the black ledge, on the highest northwest side, 715 feet; and to the bottom of the lower pit, 1,077 feet, (mean of two calculations). This makes the depth of the lower pit at that date 362 feet; in addition to which he says that there were 43 feet more to the surface of the liquid lavas.

We thus know that the down-plunge was a fact; and using as evidence only the measurements of Mr. Douglas, and noting that they were made at least a year and a half after the eruption, it was larger both as to depth and breadth than that of 1840. Hence the eruption of 1832—instead of being "a very small one, only remarkable from the fact that the fissure from which it emanated opens at a level of more than 400 feet above the present lava-lakes" with, "so far as known," "no sympathy" "within the lavas of Kilauea"*—was one of Kilauea's greatest, although not registered, so far as known, in any outside stream of lava.

b. Condition after the eruption.—Mr. Goodrich describes the Great Lake at the south end as "60 or 80 rods long, and 20 or 30 rods wide," about 20 feet below the brim; "the whole mass of liquid and semi-fluid lava was boiling, foaming and dashing its fiery bellows against the rocky shore; the mass was in motion, running from north to south, at the rate of two or

* Report of Captain Dutton, p. 124, referring to the eruption near Lord Byron's Hut.

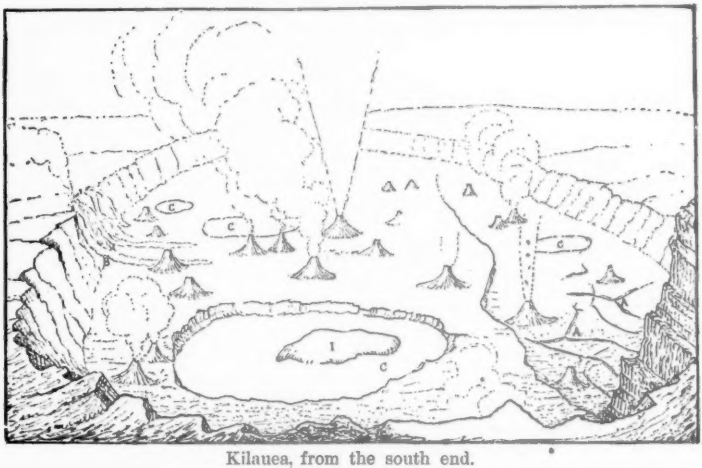
three miles an hour, boiling up as a spring at one end and running to the other." Mr. Alexander, while in the crater four months later, found this lake, "the principal furnace, not in lively action," and ascended, much disappointed; but by the time he had reached the summit, "the grand crater commenced furious action, spouting with a roaring sound, streams of melted lava far into the air." The next day he went again to the bottom, and direct to the great boiling caldron two and a half miles distant," and found it "3000 feet long and 1000 feet wide, tossing its fiery surges 40 or 50 feet into the air." He went to the brink of the lake, but left it on account of the fumes, and three minutes afterward the spot was covered with the lavas of an overflow, "which," he says, "seemed to pursue us as we hastened away." It is important to observe that uniformly the "far into the air" and similar expressions in the general descriptions of travelers become, when put in figures, not far from 30, 40 or 50 feet of actual height.

Mr. Douglas, whose visit was in 1834, reports (XI) that he found two great boiling lakes in the crater, a northern 319 yards in diameter, and a southern 1190 by 700 yards in area, heart-shaped in form. The great southern lake was "at times calm and level, the numerous fiery-red streaks on its surface alone attesting its state of ebullition, when again the red hot lavas would dart upwards and boil with terrific grandeur, spouting to a height which from the distance at which I stood (on the west wall) I calculated to be from 20 to 70 feet. Close by stood a chimney above 40 feet high which occasionally discharged its steam as if all the steam engines in the world were concentrated in it." There were other chimneys over the bottom, some active and others comparatively quiet. In each of the large lakes the lavas had an apparent movement southward, the velocity of which Mr. Douglas measured (by throwing on a block of lava and seeing how long it took to go 100 yards) making it nearly 3¼ miles an hour.*

c. Filling of the pit after the eruption of 1832.—On the 8th of

* Mr. Douglas's testimony with regard to the Hawaiian volcanoes has been doubted because of his incredible account of what he saw at the summit crater in a letter to the eminent botanist, Dr. Hooker. But I find that injustice has been done him. His *Journal* of his visit to the summit (IX*a*), evidently written by him at the time of his observations, represents the crater as having been long quiet. While at Honolulu, over three months later (May 3), he wrote Capt. Sabine on his various physical investigations and barometric measurements, and gave him the same facts as to the summit crater that he has in his Journal, and partly in the same words. Only three days later (May 6) he wrote his letter to Dr. Hooker—a reasonable letter in all parts excepting its description of the terrific activity and immense size of the Mt. Loa crater. His words indicate a mixing up and magnifying of what he had seen at the Kilauea and summit craters, which can be explained only on the ground of temporary hallucination. Mr. Douglas was an excellent Scotchman, and all the rest of his writings are beyond questioning.

May, 1838, about six years after the eruption, Captains Chase and Parker were at Kilauea. An account of what they saw was written by Mr. E. G. Kelley from their statements, submitted to them for approval, and afterward published in this Journal (X), with a plate from their sketches, but redrawn unfortunately by a New Haven artist who evidently had Vesuvius in his thoughts. An outline copy is here introduced. It was taken at the south end looking northeastward, and has the Great South Lake in the foreground. There is no black ledge on the



Kilauea, from the south end.

west or north side; and to the left instead of a black ledge there is a depressed plain, 40 feet below the general level; the part of it AA was flooded by lavas after having been passed over by the party. The crater was unusually active; there were 26 volcanic cones, 20 to 60 feet high, eight of them throwing out cinders, red hot lava and steam, and six lakes of lava (*c*), including the Great Lake "occupying more space than all the rest."

Not far from the center of the Great Lake there was an island, I, of black solid lava which "heaved up and down in the liquid mass" and "rocked like a ship on a stormy sea." This is the first mention of a "floating island." The descending streams at B are described as streams of sulphur, but as this is not possible they were probably lava-streams in part colored yellow.

The same year, in August or September, Count Strzelecki (who later visited New South Wales), was at the crater (XI). He made some barometric measurements over the region, and

determined the height of the north-northeast wall down to the "boiling surface of igneous matter" to be 600 feet, and makes no mention of a black ledge. He describes six craters with boiling lavas, four of which were only 3 or 4 feet high, a fifth, 40 feet, the sixth 150; the first five as containing 12,000 square feet each, while the sixth—which he says is called "Hau-mau-mau"—contained nearly a million. He alludes plainly to the ebullition over this great lake in the expression "ceaseless impetuosity and fury." He states that the lava sank and rose in all the lakes simultaneously; which is not always true.*

On the 16th of September, 1839, Captain John Shepherd, R. N., visited Kilauea (XII). He speaks of the black ledge as "obliterated;" of cones 20 to 30 feet high, whence issued vapors and lava with loud detonations; of a lake of lava toward the *east* side one mile long and half a mile wide within a cone 100 feet high, from the summit of which he saw the expanse of liquid lava in violent ebullition. He also mentions that the lavas had an apparent flow from south to north, and adds, "caused by the escape of elastic fluids, throwing up the spray in many parts 30 to 40 feet."

5. BEFORE THE ERUPTION OF 1840.—Mr. Coan states (XIII) "on the testimony of many natives" that in the latter part of May, for a week previous to the eruption, the interior of Kilauea was "one great sea of liquid lavas;" which signifies the existence of many active cones and boiling lakes over the bottom and extensive outflows from the lakes and from opened fissures. He remarks, further, that the ground about Kilauea so trembled from the action below that the islanders avoided the path along the verge of the crater.

There was indubitable evidence at the time of my visit, in November, five months after the eruption, of a recent flooding of the black ledge with lavas, in the tortuous scoria-covered streams of cooled lava that covered it.

6. THE ERUPTION OF 1840.—No intelligent observer was present at the eruption. Mr. Coan, then a resident of Hilo, returned home from Oahu in July, and his first account of it appeared in September of that year. He found that, through

* Count Strzelecki's note in the Hawaian Spectator occurs in the number for October, 1838, which number also states that he was visiting various portions of the Pacific in H. B. M. S. Fly. It differs widely from the report in his own work, in making the area of the largest lake 300,000 square yards, and those of the smaller "about 5,700 square yards each." His volume is the later publication, and should set aside the newspaper note. Count Strzelecki, in this volume, describes the terraces around the Kilauea crater as vast platforms; makes the height above the sea-level of the north-northeast side of Kilauea two paces from the edge of the precipice. 4,109 feet and 600 feet above the fires below; and observes that this is 950 below the brim of the *ancient* crater, the highest point of which he made 5,054 feet, and its circuit 24 miles. He thought he saw evidence that this greater crater was formerly brimfull of molten lava.

the discharge of lavas and a consequent down-plunge in the crater, there was again a lower pit with a black ledge. He gathered facts showing that the eruption began on the 30th of May, made itself apparent at intervals down the eastern slopes of the mountain, finally broke out as a stream twelve miles from the coast and flowed into the sea just south of Nanawale; and that the flowing continued for three weeks. The condition of the crater in November, the time of my visit, agrees well with the view in the accompanying Plate (Pl. XII) which was taken two months later. The route to the seashore was surveyed by the officers of the Expedition in January, and less perfectly by myself in November.

My failure to survey the whole route of the lavas to the sea-coast and investigate other parts of Hawaii was in obedience to orders. The vessel of the Expedition to which I was attached—the sloop-of-war "Peacock"—was at the time already under sailing orders for hydrographic work in the equatorial regions of the Pacific; and, although the geologist of the Expedition, I was required to go off with her, away from the most important field of geological investigation in the ocean. Only a week was allowed me for Hawaii. I left the region of volcanoes with a silent protest—the only safe kind—but found compensation through work in another field; and though an old field to me, it was one of unexhausted delight and instruction—the coral islands of the central Pacific. I was enabled to add much to the knowledge of reefs, corals and crustaceans which I had gathered during the preceding season in the Paumotu, Society, Samoan, Friendly and Fejee Islands, by excursions and studies in the Union Group of atolls, the Phœnix Group, the Kingsmill or Gilbert islands, and others. Captain Wilkes had once (while we were off Patagonia) sent me word, when I was seeking information from the log-book of his vessel as to the winds of a Cape Horn gale, that he had that department in charge. At the Hawaiian Islands it was made to appear that at his pleasure, he had the geological department also in charge, although he knew nothing of the subject. The "Narrative," however, was intended to include all departments; and the energetic commander was never conscious of incapacity in any direction.

7. After the eruption of 1840.—*Size of the Crater.*—Capt. Wilkes states, on page 123 of the 4th volume of the Narrative, that the "black ledge surrounds it [the crater] at the depth of 660 feet, and thence to the bottom is 384 feet;" and four pages beyond: "the black ledge is of various widths, from 600 to 2,000 feet." The black ledge "was found [to be] 660 feet below the rim." The floor of the crater "was afterwards found to be 384 feet below the black ledge, making the whole depth 987 [1,044 ?] feet below the northern rim."

The observations here reported were made in December, 1840, the party leaving on the 18th for the top of Mt. Loa. Other observations on Kilauea were made by Capt. Wilkes and his officers just a month later, in January; and these include a topographic survey of the crater by Capt. Wilkes, who says: "I measured my base and visited all the stations around the crater in their turn." On page 175 it is stated that the observations of one of the officers of the expedition, Lieut. Budd, made the depth to the black ledge 650 feet, and thence to the bottom 342 feet, whence "the total depth 992 feet." On page 179, we learn that Lieut. Eld was instructed to make the measurement of the depth, "as I was desirous of proving *my own* as well as Lieut. Budd's observations;" and then follows the remark, "The measurements coincided within a few feet of each other." Had the precise numbers obtained by Lieut. Eld been reported we might be able to remove the doubts left by the varying statements. But the fact that Lieut. Budd's results are inserted by Capt. Wilkes on his own map of the crater is a strong reason for believing that the coincidence was between the results obtained by the two Lieutenants.

I add here a few words from my own report, on the surface about Kilauea, on the stratification and rock of the walls and the absence from them of scoria, and on the escaping vapors of the Great Lake. "The country around [Kilauea] is slightly raised above the general level, as if by former eruptions over the surface." The walls "consist of naked rock in successive layers" "and look in the distance like cliffs of stratified limestone." The rock is a heavy compact dark gray to grayish black lava [basalt] containing usually fine grains of chrysolite; and no layers of scoria like that making a crust of two to four inches over the solidified lavas from the lava-lakes, intervene even in the walls of the lower pit, each new stream having apparently melted the scoria-crust of the layer it flowed over. While the cooled lava-streams over the bottom were of the smooth-surfaced kind [and would be called pahoehoe] there was the important distinction into streams having the scoria-crust just mentioned, and those having a solid exterior and no separable crust, pointing to some marked difference in conditions of origin. "The vapors rising from the surface of the Great Lake were quite invisible until reaching an elevation where part became condensed by heat" (p. 179); here began "a column of wreaths and curling heaps" and upon this column "the broad canopy of clouds above the pit seemed to rest" (p. 172).

[To be continued.]

Art. XLV.—*Special Processes of Research;* by G. K. Gilbert.

[Presidential Address read before the American Society of Naturalists at Philadelphia, December 28, 1886.]

Mr. President and Gentlemen:—A year ago your suffrages made me my own successor in office. To that fact is due our present relation of audience and speaker, and to that fact is also due the subject of my discourse. My re-election was a phenomenon of so surprising nature that I have only recently ceased to frame explanatory hypotheses. One theory after another was subjected to such tests as were available, and was proved to be untenable—until finally it occurred to me that my address last year was not thrown open to debate, and that the nomination of officers came soon after it. It was then evident that the treatment of the subject of the address had not been so clear and convincing as was desirable, and that you had delicately given me an opportunity to supplement it. I embrace the opportunity.

Our subject last year included the general process of scientific research.* To-day endeavor will be made to illustrate the general process by a description of certain special methods of its application.

When one of our citizens first comes into relation with the Chinese, he finds great difficulty in distinguishing and recognizing individuals. This is not because marks of discrimination are wanting—the Chinaman from a different province has no such trouble,—it is merely that he unconsciously groups together all the features of face and costume as strange. The *common* features by their strangeness hold his attention, and until this strangeness has passsd away, he does not automatically catch the *individual* features. A year ago we gave attention to the common features of research and saw it as a unit. If now we should attend instead to the features of difference, we would find an immense assemblage of individual operations, devices, and other details, a limited number of formulated procedures applicable to groups of special cases, and a great organized, though ever enlarging, system of research, in which each special procedure assumes its proper coöperative function. I shall attempt neither the enumeration of the details, nor the characterization of their groups, nor the demonstration of the organized system. I could not if I would, and if I could, time would not permit. What I shall attempt is this: first, to follow for a time the course of an elaborate, carefully planned investigation of a complex subject, analyzing its

* This Journal, vol. xxxi, p. 284, April, 1886.

methods by the way; and second, to describe a special system of procedure which, like the rule of three, stands ready to assist the student whenever a suitable occasion arises.

The investigation chosen for my first purpose is that of thunderstorms, as undertaken by the New England Meteorological Society. It is planned by the society in a broad way and has among its objects the classification of the storms (provided the discrimination of distinct types is possible), the determination of their mechanism, the discovery of their causes, and the prediction of their occurrence. An account of the work, a summary of the first season's observations, and an outline of the conclusions deduced therefrom have been published by Professor Davis. I have selected this research as an illustration of my theme, partly because it belongs to the living present and is somewhat familiar to most of my audience, and partly because the methods employed and the reasons for their adoption have been set forth by Professor Davis with exceptional fullness and clearness.*

You are not to expect an abstract of his papers, but only of such passages as are necessary to an understanding of the general nature of the considerations determining, first, the formulation of the scheme of observations, and, second, the methods of classifying the observations after they had been made. My discussion of the scheme of observations will be introduced by a general account of the factors determining its principal features, and by an account of the features themselves, after which an analysis will be attempted of the logical relations of the two.

The system of atmospheric phenomena which centers about a large area of low pressure is called a cyclonic storm. One of these storms usually has a diameter of several hundred miles, and moves across the country so slowly that an entire day is spent in passing a single point. Their nature was discovered by comparing together simultaneous observations of atmospheric phenomena made at numerous stations scattered over a large area; and a knowledge of this character is utilized, as you all know, by the national weather bureau in the prediction of storms and other weather features from day to day. To obtain the data necessary for prediction, observers are stationed at a large number of points distributed at intervals throughout the United States; and it is arranged that they record a certain set of atmospheric phenomena at three concerted times in each 24 hours. Before the New England society began its

* On the methods of study of Thunder-storms; by W. M. Davis. Proc. Am. Acad. Arts and Sci., vol. xxi, p. 336.

Thunder-storms in New England in the summer of 1885; by William Morris Davis. Proc. Am. Acad. Arts and Sci., vol. xxii, p. 14.

work, it was known that thunderstorms, although too large to be fully observed from a single station, are too small to be investigated by means of so coarse a mesh of stations as that of the national weather bureau. A thunderstorm observed at one of these stations frequently escapes notice at the other stations of the vicinity, while many of them occur between stations and are thus entirely omitted from their records. It was known that the local phenomena of a thunderstorm are of comparatively brief duration, so that the tri-daily observations do not afford a complete record of their occurrence. It was known that some thunderstorms move across the country, appearing successively at different points. It was known that they are characterized by electric discharges as well as by rain, wind and temperature change, and it was known that their occurrence is more frequent in summer than in other seasons of the year. It was believed or hoped that some conspicuous, readily observed feature of their transit might be found so persistent and constant in its relation to the aggregation of phenomena constituting the storm that it could be used for the purpose of tracing out the path and general form of the meteor. The society was unable to pay its observers for their services, and it recognized the fact that those who might voluntarily coöperate with it must not be overtaxed, or they would withdraw their aid.

With these considerations, and doubtless many others, in view, the work was planned and organized. The initial steps were the arrangement of a system of stations for observation, and the preparation of schedules of phenomena to be observed. A large number of resident observers were engaged, so distributed that the interspaces between stations were much smaller that in the system of the Signal Service. Provision was made for observations at very short intervals of time during the approach and passage of thunderstorms, but no record whatever was required, except a general negation, on days when no thunderstorms occurred. The work was restricted to the summer months. The observers were classified in such way that the greater number were called upon to record but few features of the storm, while a few who were able and willing to bestow much time and attention were instructed to make very full and minute records. The schedule of observations included, besides numerous other features, a number of definite events, namely, the time of the first rainfall, of the last rainfall and of the heaviest rainfall, the time of the first thunder heard, and of the loudest thunder.

Looking at this organization for observation from our special point of view, we are able to group the considerations determining its details in four categories. In the first place, there

was a certain amount of antecedent knowledge with respect to the subject of investigation, and this determined a large portion of the scheme; thus the nearness of the stations was dictated by approximate knowledge of the size of the storms to be observed. In the second place, certain hypotheses were entertained in regard to the phenomena, and these had their influence; for example, it was tentatively postulated that the beginning of rainfall bore such a constant relation to the storm as a whole that the timing of it would afford a record of the progress of the storm. In the third place, analogy with other researches had its influence; a certain resemblance was recognized between thunderstorms and cyclonic storms, and the general system of investigation was modeled upon that which had proved successful in the study of the larger meteors. Finally, numerous features of the system were determined by what may be regarded as obstacles to observation. The limited endowment of the investigation was such an obstacle and occasioned the restriction of observation to a certain season, the further restriction to the actual period of storm occurrence, and also the classification of observers.

This classification of considerations controlling the organization of the research is believed to be comprehensive, and applicable to any other systematic research, but it will not serve the purpose of dividing into groups the details of working plan to which the considerations give rise, because nearly every detail is the joint product of considerations falling in two or more categories; and it should be observed also that its categories are not mutually exclusive. The consideration of obstacles—or practical limitations—never occurs alone, but merely modifies the procedure indicated by other considerations. The consideration of analogy cannot stand alone, because analogy exists only in virtue of some knowledge or supposed knowledge or hypothesis with reference to the nature of the subject of research. And again, considerations of antecedent knowledge and of hypothesis have no clear line of demarcation, for the practical discrimination of knowledge and hypothesis, however sharply they may be divided in thought, is beset with insuperable difficulties.

Returning to our illustration, we note that the published plan of observation includes no mention of barometric pressure; and that the only observations touching the electric condition of the atmosphere are those on lightning and thunder. It is easy to understand that these omissions are referable to the obstacle of expense, and we may also assume, although we have no warrant in the publications of the society, that such observations will be made at some future stage of the investigation, when accumulation of knowledge and hypothesis has

made it possible to develop a plan whereby a small number of the necessary instruments can be so distributed as to perform their work effectively and economically. This assumption of our own is based on the analogy of other investigations, for it is a common feature of researches that the preliminary results determine the scope and field of subsequent observation. A research is the exploration of an unknown land, and neither the route nor the goal can be foreseen. The explorer climbs the hill before him, and from the vantage of its summit selects the most promising course for the next stage of his journey.

One of the most important obstacles encountered in the work of the society arises from the difficulty of making observations at a distance from the surface of the earth. A thunderstorm involves a mass of air of very considerable vertical dimension, and the ideally complete system of stations would include many more points in mid-air than upon the ground. Observations from balloons, though within the range of possibility, are limited by expense and danger, and would moreover be conditioned by uncertainty as to location at all points within the storm cloud. The society has thus far attempted only terrestrial stations, but it endeavors by indirect methods to learn something of what is taking place at greater altitudes. The wind cannot be directly observed there, but floating objects can, and observers are therefore instructed to watch the motions and observe the positions of clouds. Temperature and moisture cannot be directly measured, but advantage is taken of the fact that a certain combination of temperature and moisture produces condensation, so that the boundary of a cloud is the locus of a certain atmospheric condition which is a joint function of temperature and moisture. The configuration of the storm cloud therefore has a certain value, and is the subject of study. It was also known antecedently that as the domain of saturation advances in the air, the resultant cloud grows, while its recession is characterized by the dissipation of the cloud. Observers are therefore instructed to record cloud formation and cloud dissipation.

The preliminaries having been arranged, observations were made during the summer of 1885, and the records of observation were placed in the hands of Professor Davis for the purpose of what is variously called "reduction," or "working up," or "digestion," or "discussion." What he did was to classify them in various ways, and observe the relations brought to light by the classification. But before he made a classification, it was necessary to select its basis. The particulars of observation were numerous. They included the intensity of the storm, the first thunder heard and its direction, the loudest thunder and its direction, lightning strokes, the first rain, the heaviest rain, the

last rain, the total rainfall, hail, the temperature of the air, the moisture of the air, the direction of the wind, the force of wind, cloud form, cloud motion, cloud height, cloud growth, and cloud dissipation; in all no less than twenty categories of items, and each item connected with a place and a time. The number of possible arrangements was indefinitely large. Any one of these particulars might be assumed as basis for the classification of any other one; or two might be assumed as joint basis, or finally the basis of classification might be some very different phenomenon, either occurring at the same time, or belonging to the same region. From this bewildering array of possibilities it was necessary to make a selection, and there was small probability that a random choice would lead to a profitable result. Considering the selection or rather the series of selections which he actually made, we are compelled to believe that they were not accidentally determined, but it is proper that I should admit in advance that the considerations I have assigned are chiefly based upon my own inference, rather than his statement.

The basis of the first classification was time, but this was merely a stepping stone to the accomplishment of a classification based on the individual storm. It was known or postulated that each storm was so short-lived that its record would be comprised in a single day, if not within a few hours. The reports were therefore sorted by days, and then examined more closely to see whether the storm records of a single day fell naturally into two or more groups.

The next classification depended, in part at least, on the hypothesis that the individual storm moves bodily across the country. Its bases were time and place jointly, and its method was graphic. Place was introduced by the employment of a map of the district; time was introduced by platting upon this map certain classes of data with reference to the times of their occurrence. By this classification different particulars of observation were tested as to their value in determining the bodily motion of the storm. For example, there was marked upon a map at the locality of each observer's station the time at which the rain of the particular storm began. Then lines were drawn connecting points characterized by the same time, or more precisely, a line was drawn for each quarter hour, the line being made to intersect all points marked with its particular time, and being interpolated among points marked with times a little earlier and later. The result was a system of lines representing the position of the rain front at equidistant times (fig. 1). The lines also showed the form of the rain front, and their order served to indicate its direction and rate of progress across the district, while the space they collectively

covered marked out the path of the rainstorm. When the times of the loudest thunder, and the times of certain other events of the storm had been similarly tested, a comparison of the results showed that the observations on the times of first rain produced the most orderly system of lines, and the rain front was therefore selected as one of the bases for the next classification.

It will be observed that the second classification, by place and time, was superposed on the first classification, by storms. The third classification was likewise superposed on the first, but not on the second, except in the sense that it used its results; that is to say, the third classification was applied to the individual storm, and substituted new bases in lieu of place and time. These bases, which may be called the horizontal axes of the storm, were the middle path and the rain front. The classification was once more graphic, and was accomplished

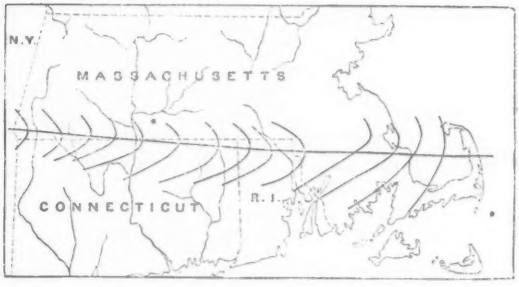


Fig. 1. Lines of synchronous rain-front, storm of July 21, 1881.

in essentially the following manner. A straight line drawn on a sheet of paper represented for any and every instant of the history of the storm, the portion of the middle line of its path momentarily included in the storm area. A curved line transverse to this represented with its proper form the line of first rain or the rain-front (fig. 2). Then observations of thunder, of heaviest rain, of temperature, of lightning strokes, etc., were platted on the same sheet, the position of each observation being determined by measurement from the axes. Its distance from the middle path axis was made equal to its distance from that path on the map showing the storm track; its distance from the rain-front axis was determined by a computation based on the velocity of the storm and the time elapsed before or after the rain-front passed the same station. If for a given instant of time a chart were prepared, showing, in their proper place relations, all the features of the storm observed at that

instant; if similar charts were prepared for all other instants of the storm's life; and if these were superposed on each other so as to bring common features together, the result would be the same as by the process just described, and this result has therefore been compared by Davis with Galton's photographic overprinting and aptly called a "composite portrait" of the storm. This composite (of which my diagram is a mere abstract) was explained and illustrated to the Society at its Boston meeting, and you will recall what an orderly presentation it gave of the complex congeries of phenomena. Its inspection afforded at once to the investigator a large body of generalizations concerning the individual storm and of hypotheses concerning thunderstorms in general.

If now we examine these three processes of classification in their relations to each other and in relation to the purposes of the investigation, I think we shall be able to perceive the considerations which led to their employment. One of the primary

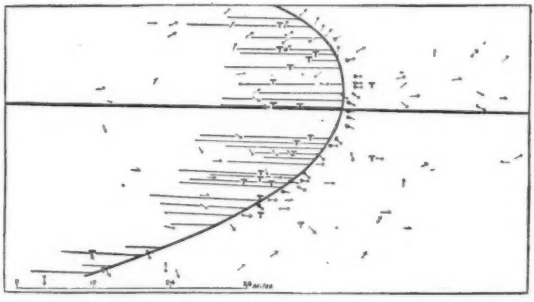


FIG. 2.—Composite portrait of thunderstorm; arrows and the number of their feathers show direction and force of wind. T, T, observation of loudest thunder. Straight lines mark observations on the width of rain area.

objects of the research was the determination of the mechanism of the thunderstorm, and this object manifestly required the study of the simultaneous phenomena of the storm. The first effort in classification was therefore the isolation of the individual storm. A natural second step would have been the selection of some moment of the storm's life for special examination, but if such examination was attempted, it met with an obstacle arising from the fact that the simultaneous observations at any one moment were so few as to be quite inadequate to the purpose. The analogy of other investigations suggested that the desired result might be accomplished by combining the observations on the individual storm without reference to time or place, but with reference to some central feature or features

of the storm itself. In the case of cyclonic storms the area of lowest pressure has been thus used, its terrestrial meridian serving as an axis of orientation. In the case of thunderstorms no such area of lowest pressure had been determined, and it was necessary to select some other feature or features to serve the same purpose. The second classification was therefore made as a means of overcoming a practical obstacle to the accomplishment of the desired classification.

The preliminary classification, or more exactly group of classifications, having been decided upon, its particular nature was determined by the antecedent knowledge that thunderstorms ordinarily move across the country, and by the hypotheses that the first rain, or the heaviest rain, or the loudest thunder, or some other definite event might be found to be so constant in its relation to the storm as to constitute a suitable basis for the third classification.

The change of basis in classification, whether it belonged to the original plan of the investigation or was devised under the stimulus of a discovered obstacle, finds its analogues not only in other researches but in other departments of human experience. The quarryman who wishes to overturn a heavy block inserts his bar beneath it wherever it finds a crevice, even though the point of insertion be not the most advantageous for his general purpose. Having done so, he lifts until there is room for the lever at the point of vantage, and then shifts his position. The algebraist by premeditation eliminates from his equations all but one of the quantities whose values he seeks, and having determined that one, undertakes with its aid the solution of one of the original or intermediate equations.

If then our interpretations are correct, the bases of clasification, like the methods of observation, sprang from analogy with other researches, from previous knowledge of the subject in hand, and from hypotheses in regard to the results, and were conditioned by obstacles.

As already remarked, the basis of classification need not itself belong to the subject under investigation. The phenomena of the New England thunderstorms may be compared with respect to distribution in time with any other phenomena or events occurring in the same time, or they may be compared with respect to distribution in place with any feature of their district. Thus it is entirely possible to group any of the thunderstorm phenomena according to the days of the week, or with reference to the daily records of marriages in London, or the fluctuations of a mining stock, or the success of the Philadelphia base ball nine, and it is equally possible to compare their distribution with the topographic relief of the country, with the density of population, with the distribution of forests,

of geologic formation, or of railroads and telegraph lines. There is in fact no limit whatever to the number of possible classifications of this nature, and as very few of them can yield other than negative results, it is evident that the investigator cannot afford to take them at random. Some criterion of discrimination is necessary, and this he finds in the employment of hypotheses. The only bases of classification affording him results of positive value are the phenomena which are connected in a necessary or causative way with the phenomena under investigation, and the only bases he can afford to test are those which hypothetically have such connection. If he entertains the hypothesis for example that arboreal vegetation induces precipitation, he will classify the rainfall with reference to the distribution of forests; and if he finds a general correspondence but suspects that it may be deceptively produced through the influence of altitude on both rainfall and forest preservation, then he will also classify both rainfall and the distribution of forests with respect to altitude. If he entertains the theory that the moon is concerned in the generation of storms, he will group his phenomena according to the phases of the moon.

We find from the record that Prof. Davis employs successively two external bases of classification. On the hypothesis that solar heat is directly concerned in the production of the storms, he groups them with reference to the hours of the day, finding a well marked correspondence. On the hypothesis that the conditions of their occurrence are produced by the more general movements of the atmosphere, he groups them with reference to cyclonic storms traversing the same district, and here again he finds a correspondence. In each case the correspondence is of such nature as to suggest other hypotheses and lead to other classifications.

In platting the data concerning rain-front on the map of the district, and in the preparation of the composite portrait of the storm Professor Davis employed what are called graphic processes; and the general graphic method to which these processes belong is of such importance in research that no apology is needed for devoting the remainder of my time to its consideration.

It is a familiar principle of analytic geometry that every equation involving two variables may, through a process of construction, be represented by a line on a plane surface. The values of the two variables are referred each to an axis, or origin of distances, and each pair of corresponding values determines the position of a point. The line drawn through or constituted by all the points is then a graphic expression of the

equation. It has many of the properties of an equation and may be discussed in a similar manner.

The subsidiary or dependent laws deduced algebraically from the written equation have a quantitative definiteness to which the platted curve can afford only approximations, but the curve yields to the minds of most men a clearer conception of the nature of the relation of the two variables than is conveyed by the equation. Its advantage is that it appeals to the eye, and thus brings a sense impression to the aid of the imagination. This however is by the way, for the application of the platted curve in research is somewhat different.

When the investigator, suspecting that two phenomena are mutually related in a constant and necessary manner, has made a series of observations affording him simultaneous quantitative values of the phenomena, there are open to him two general ways for the classification of his observations and the drawing of the proper inferences. Pursuing what may be called the written or mathematical method, he writes the observed quantitative values of one phenomenon in a column in the order of their magnitude, and the corresponding quantities expressing the other phenomenon in a parallel column. He then inspects the numbers of the second column to see whether they constitute a series. If their arrangement is quite irregular, he infers that the two phenomena have no constant relation; but if he detects a greater or less amount of order among the numbers, he assumes the existence of a law, and endeavors to ascertain its nature by discovering its mathematical expression. He first assumes more or less arbitrarily or hypothetically the general form of the equation expressing the relation of the phenomena, and by substituting the observational values successively in this formal equation, he obtains a number of numerical equations from which a single one is deduced by the method of least squares. The resulting formula expresses the law connecting the phenomena with a degree of precision which depends on the consistency of the observations; and by another mathematical process he can obtain a numerical expression representing this degree of precision. The two expressions will enable him for any given value of one variable or phenomenon to compute the corresponding value of the other, and also to compute the probable error of this value.

If on the other hand he employs the graphic method, his procedure is ordinarily as follows: Upon a sheet of cross-barred paper he assumes the lines running in one direction to represent equidistant values of one of the observed phenomena, and the lines running in the transverse direction to represent equidistant values of the other phenomenon. The scale assigned upon the page to the numerical values is unessential, and is

adjusted purely to considerations of convenience. Then for each pair of simultaneous values of the phenomena he finds the intersection of the corresponding lines and marks the point with a dot. If the value of either phenomenon falls between the numbers represented by two adjacent lines, the position of the dot is correspondingly interpolated. The relations of the dots to each other are then considered by inspection. If they are irregularly scattered over the sheet, the absence of a law is inferred. If they fall in line, either accurately or approximately, the existence of a law is demonstrated. In that case a line is drawn through or among the platted points, and this line is an expression of the law or relation sought. The investigator may or may not proceed to the computation of the algebraic equation. As a rule such procedure is profitable only when the platted points fall well in line, for it is only then that the proper form of equation can be selected with confidence, and without a knowledge of that form extrapolation is hazardous. For purposes of interpolation the free hand curve drawn among the platted points is practically as serviceable as the algebraic equation.

Ordinarily, as in the employment of section paper, the lines used to represent numerical values are straight, parallel and equidistant, and the two sets intersect at right angles, but none of these characters are essential to the graphic method. The lines may be curved, they may converge, their interspaces may follow any law of increase or decrease, and the two sets may intersect at any angle. Nor is it essential that more than one line of each set be drawn—indeed, in a large group of practical examples even these are omitted, the edges of the paper standing for them. The graphic notation is thus highly elastic, adjusting itself freely to the convenience of the investigator.

It is equally versatile in the character of the results it attains. Even when the phenomena do not practically admit of algebraic expression, and no representative line can be drawn upon the graphic chart, the form of the area occupied by the dots, or some other feature of their distribution may convey a meaning. If one in ignorance of the principle of the psychrometer should plat upon a sheet the simultaneous observations with a dry bulb thermometer and a wet bulb thermometer, representing the dry-bulb readings by abscissas and the wet-bulb by ordinates, he would find that the group of determined points could not be connected or generalized with any degree of approximation by a line, but if the number of his observations was large, he could not fail to perceive that the area occupied by the dots was definitely limited above by a diagonal straight line passing through the points of intersection of the lines representing

equal temperatures on the two thermometers. He would thence legitimately infer that the wet bulb temperature is never higher than the coincident dry-bulb temperature.

Diagram No. 3 is copied from one prepared by Professor Call to illustrate the relations of size exhibited by certain collections of the shell *Helisoma trivolvis.** The ordinates represent lengths in millimeters, the abscissas, which have the same scale, represent breadths; each circular dot shows the length and breadth, and thus stands for, an adult individual collected from a small lake in Utah; each square dot represents an adult individual collected from a late Quaternary deposit in Nevada. Now it is evident by inspection that these dots do not form even approximately a straight line, and we therefore infer that in this species the length does not bear a constant ratio to the breadth. It is further evident that the area covered by the circular dots is quite distinct from that covered by the square, and that it is farther from the origin. The modern specimens are therefore distinctly larger than the fossil, and this difference is, for the two localities in question, of a constant nature. Thirdly, each group of dots is horizontally elongate, the distal end of the group being slightly—and only slightly—higher than the proximal, and from this we learn that at each locality the length is more constant than the breadth, variation of size being chiefly, though not entirely, confined to the lateral dimension. Now there can be no question that all of these results might have been obtained by mathematical methods, provided they had been suspected in advance, but without antecedent hypothesis they would never have been discovered, while the graphic method furnishes the information without the aid of leading questions.

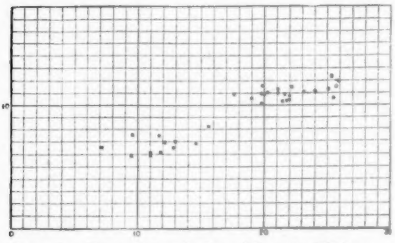


FIG. 3.—Length and breadth of *Helisoma trivolvis.*

This example illustrates also a second and higher office of the graphic method, for it essentially involves more than two variable phenomena. It not only shows the relation between the length and the breadth of this shell, but the variation of this relation with geologic horizon. In the black dots are compared the length and breadth of the round *Helisoma trivolvis*, in the square dots the corresponding dimensions of the same

* On the Quaternary and recent mollusca of the Great Basin; by R. Ellsworth Call. Bul. No. 11, U. S. Geol. Survey, Pl. III, Diagram II.

shell from the geologic deposit. The two relations might have been exhibited upon separate sheets, but as they are relations between similar quantities, we can by employing the same scale plat them upon the same sheet, and thus platted, we are enabled to compare them with each other.

It is a general principle that if we have a series of observations showing the relations of phenomena A and B and another series showing the relations of A and C, we may by platting them upon the same sheet and employing the same scale in the representation of the values of the common phenomenon, A, make a sort of comparison between B and C. The units of measurement for B and C may be of different kinds, and even if of the same kind, may be of different orders of magnitude, and it is not ordinarily necessary to establish any correspondence in their scales. Neither is it necessary that the zeros of their scales have the same position.

In this manner Professor Loomis has compared the mean daily range of the magnetic declination with the relative extent of dark spots on the surface of the sun by the aid of their common relation to time;* that is to say, using time for his scale of abscissas and the relative extent of spots as a scale of ordinates, he has platted a curve showing the relation of spot extent to time. Then upon the same sheet and with the same scale of abscissas he has platted a curve in which the ordinates represent the daily range of magnetic declination. The second curve shows the relation of magnetic declination to time, and the two curves exhibit to the eye whatever correspondence or discordance there may be between the time relation of the magnetic declination, and the time relation of the extent of sun-spots. Again he has made the ordinates represent frequency of auroral displays, and has thus produced a curve showing the relation of auroral frequency to time, and this curve he is able to compare with each of the others. There is indeed no limit to the number of relations which may be compared in this way, provided only that one system of coördinates, either abscissas or ordinates, remains unchanged in meaning and scale. Mr. Schott in his discussion of the temperatures of the United States has compared the sun-spot curve with four curves representing secular changes of temperature at as many stations, the abscissas representing the common factor time, and the ordinates standing for temperatures in the case of four of the curves, and for relative frequency in the case of the other.†

* This Journal, III, vol. v. p. 346.

† Tables, distribution, and variations of the atmospheric temperature in the United States, etc.; by Charles A. Schott. Smithsonian Contributions. Plate facing p. 310.

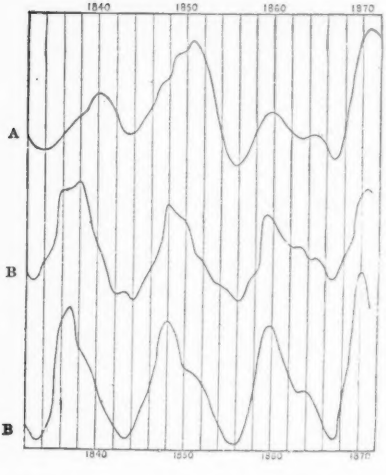


FIG. 4.—*A*, number of auroras. *B*, range of magnetic declination. *C*, relative extent of spots on the surface of the sun.

Looking at these curves from the algebraic standpoint, we see that they do not correspond to a single equation between three or more variables, but to a group of equations with one variable in common, and with one other variable in each equation. If we combine two of the equations or curves in such way as to eliminate the common variable, we obtain an equation or curve showing the relation between the two other variables. It is frequently advantageous to do this, but not always; and it is not ordinarily advantageous to do it when the common variable is time. I have copied in fig. 4 a portion of Professor Loomis' curves, and it is evident by inspection that there is a marked correspondence between the maxima and minima of the three curves. I have also combined the data employed in the construction of the upper curve (auroral frequency) and the lower curve (extent of sun-spots) in such way as to eliminate the common element of time, that is to say, I have (in fig. 5) platted for each year the relation of auroral display to extent of sun-spots, the ordinates representing frequency of auroras, the abscissas the extent of solar spotting. It would hardly be suspected from the arrangement of these dots that the two phenomena are in accord.* Looking again at fig. 4, we see that while the minima of the upper curve correspond very closely with the minima of the lower, the maxima lie farther to the right. If the phenomena are really connected in a causal way, it would seem that the auroras are the effect, and that they are brought about by some chain of causation involving time.

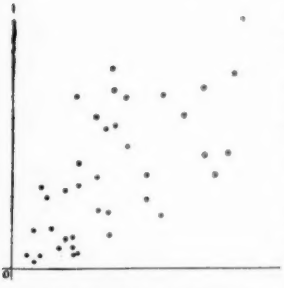


FIG. 5.—Direct comparison of auroras with sun-spots.

* My illustration is subject to a qualification, which, though unessential, should be stated. In fig. 5 each ordinate represents the number of auroras observed

The next higher division of the graphic method is homologous with the algebraic equation containing three unknown quantities, and is employed in the discussion of a phenomenon with reference to its simultaneous relations to two other phenomena. If in an equation between three variables we make one of the variables successively equal to 0, 1, 2, 3, etc., we obtain a series of equations between the remaining two variables. Each of these equations is the equivalent of a curve, and we may plat the equivalent curves upon the same sheet of paper, referring them to the same coördinate axes. They constitute a system, and they collectively express, in connection with the other systems of lines on the paper, the original equation between three variables. If the sheet upon which they are platted is ordinary engineer's section paper, then we may say that the vertical lines of the paper represent equidistant values of one variable, the horizontal lines equidistant values of a second, and the system of curves equidistant values of the third. Definite values being assigned to either two of the variables, the corresponding value of the third may be found by inspection. This principle is extensively applied in abridging the labor of computation where a large number of results are to be derived by means of the same formula.

It is possible that the nature of this system of curves will be more clearly apprehended if we approach it by a route involving more of geometry and less of algebra. An equation between three variables is the algebraic equivalent of a surface, either plane or curved. Let us think of such a surface as forming the uneven top of a solid body whose base is flat and square, and whose sides are vertical. Horizontal distances along the sides in one direction correspond to values of one variable, and in the transverse direction to those of another, while vertical distances correspond to values of the third. Now intersect the solid by a system of horizontal planes, each one at a height above the base determined by an integral value of the third variable. Each plane will cut the upper surface in a different curved line, and each of these lines will be a contour of the surface. Now move all these lines vertically downward to the basal plane, and there is formed on that plane a contour map of the upper surface of the solid. This contour map is identical with the system of curves obtained through the algebraic manipulation of the equation. The relation between the three variables has thus three separate but equivalent expressions

(from a certain system of stations) in a single year. In fig. 4, curve A, each ordinate represents the mean of the numbers observed in three consecutive years. That is to say, Professor Loomis "smoothed" the curve by a process making each ordinate an equal function of the observations of the corresponding year, the preceding year and the following year, while I employed the unadjusted data of observation.

besides its verbal statement. It is expressed by the equation, by the curved surface, and by the system of plane curves, or the projection on a plane of the contours of the curved surface.

The allied process in the conduct of research is as follows: Upon a sheet of paper two systems of lines representing equidistant values of two variable phenomena are drawn or conceived to be drawn. Points representing observations are then added, their positions with reference to the two systems of lines being made to indicate the quantitative observations of the two phenomena, and figures, or other equivalent notation, being employed to indicate the simultaneous quantitative observations of the third phenomenon. Lines are then drawn connecting those dots which bear the same figures, and it is arranged, by the aid of interpolation, that these lines represent equidistant values of the third variable. The chart thus prepared shows by inspection the relations of the third phenomenon to the other two. The isobars on our weather maps are of this nature. Space in two of its dimensions constitute in this case two of the variables; we may say for convenience that one variable is latitude and the other longitude. The third variable is barometric pressure. The lines representing meridians and parallels may or may not be drawn upon the map, and if they are drawn, their character, as straight or curved, will depend upon the nature of the projection of the map. Another illustration is found in Davis's rain-front map, (fig. 1.)

It will be convenient to have distinctive terms for the line, corresponding to two variables and for the system of lines corresponding to three, and I venture to propose for the first the name *nomogram*, or line representing a law, and for the second *isogram*, a title connecting it with its familiar examples in the isobaric, the isothermal and the isohyetal curves.

Isograms admit of combination in the same manner as nomograms, but in their case it is essential that *two* of the variables be common to all. Upon our daily weather maps the isobars and isotherms are both platted with reference to latitude and longitude, and we are thus enabled to compare in a direct and simple manner the areal phenomena of temperature with the areal phenomena of pressure. The weather map is the logical equivalent of two equations, each including three variables, the equations agreeing in two variables and differing in a third.

The general case of an equation of four variables has not yet found graphic expression, although some special formulæ with four or even five variables have been reduced to graphic form for the purposes of the computer.

I am not aware that the graphic method has been used in research to express a relation involving more than three independent variables. In an investigation by Prof. Thurston into

the comparative strength of the different members of a certain group of alloys, he has platted the strength by means of an isogram whose points are fixed by three coördinate lines, each representing the ratio in which an ingredient enters into the alloy.* But the ratios of the three ingredients are not independent variables, since any two being known, the third may be determined. His method of platting employs three coördinate axes arranged in the form of an equilateral triangle, but one is redundant; the same result would be attained if the ratio of one ingredient were ignored and the ratios of the other two were referred to two coördinate axes intersecting at an angle of sixty degrees. I would not be understood to criticize this method of projection unfavorably—it is a singularly happy adaptation of a general method to a special case; I merely claim it as essentially a normal isogram. It may be added that in the general theory of projection by trilinear coördinates the redundancy of one set of coördinates is recognized by mathematicians.

Prof. Davis's composite portrait (fig. 2) is the rational equivalent of a group of equations, each containing three variables, and all agreeing in two variables which they hold in common. It differs from the normal isogram in that the lines representing the third variables of the several equations are undrawn. One of the common variables is distance from the middle path of the storm, the other is distance from the line of rain-front; the remaining variables, which are severally functions of these two, are the phenomena of wind, temperature, thunder, lightning stroke, etc.

The composite photograph devised by Galton also finds place here. In his method a number of pictures, over-printed on the same sheet of paper, have two points in common. This is equivalent to giving them the same origin of coördinates, the same directions of coördinate axes, and the same scale.

There is also a type of graphics bearing the same relation to the isogram that Prof. Call's group of points bears to the nomogram. It is illustrated by charts of geographic distribution in which the data platted either do not admit of, or are not subjected to, quantitative gradation. Of this nature is a chart showing the positions of the volcanoes of the world.

The graphic processes thus outlined and classified constitute essentially the graphic method as employed in research, but there are numberless details and devices, having the general nature of short cuts, in the invention of which any one will become fertile who makes extensive use of the general method.

* The strongest of the bronzes, a newly discovered alloy of maximum strength. By Robert H. Thurston. In Rept. U. S. Board appointed to test iron, steel and other metals. Vol. ii, p. 133.

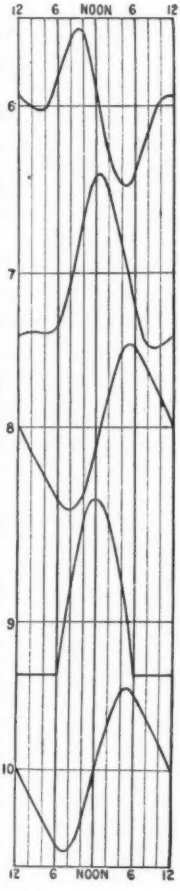
For example, in describing Prof. Davis's preparation of the composite portrait, I have represented him as computing certain distances from knowledge of the corresponding times; but in point of fact he saved himself that labor by a very simple graphic expedient. The velocity of the storm being approximately uniform, distances in the direction of motion were proportional to times; and as distances on the composite were proportional to distances on the ground, they were likewise proportional to times. He therefore graduated a time scale on a strip of paper, laid it on the composite sheet parallel to the storm-track axis and at the distance corresponding to a particular station, slid it along until the graduation for the time of first rain at that station was over the rain-front axis, and then marked on the composite opposite the proper time graduations all the other observations made at that station.

Another of these special devices it has fallen in my own way to employ, and I will take the liberty to describe it, for while its field of application is narrow, it was found exceedingly useful within that field. Whether it is novel, I am not informed. It is a method of graphic integration allied in principle to the algebraic process known as mechanical quadrature.

Of the many variations to which the pressure of the atmosphere upon the barometer is subject, there is one having a daily period. Early in the morning the barometer rises, then during the middle of the day it falls, reaching a minimum in the afternoon, and there follow during the night one or more minor undulations. This oscillation was recognized long ago, and it is the subject of an extensive literature, and many theories have been framed to explain it. One of these, proposed by Espy,* appeared to me so plausible as well as simple that I undertook some years ago to test it. The theory is this: During the day the atmosphere, being warmed by the sun, is expanded and made to occupy greater space. Every stratum except the lowest is thus moved upward, and as the air is endowed with mass, time is consumed in putting it in motion. While the expansive force is acting, and so long as fully equivalent motion has not been produced, there is a reaction downward, causing a rise of the barometer. Conversely, when the rate of heating or the rate of expansion diminishes, the upward momentum of the air produces the reverse effect, a defect of pressure on the barometer. The addition to the normal pressure of the barometer is greatest, not in the afternoon when the temperature of the air is highest, nor yet at noon when the heating of the air is most rapid, but in the morning when the increment to the rate of heating is greatest. Now the momen-

* Fourth Meteorological Report. Foot note to p. 11.

tary rate of heating is the differential of the temperature, and the momentary increment to the rate of heating is the differential of the rate of the heating, or the second differential of the temperature. If then the variation of pressure is proportional to the increment of the rate of heating, it is also proportional to the second differential of the temperature; and an equation or curve expressing the law of the diurnal oscillation of pressure should by a double integration yield the equation or curve expressing the law of the diurnal oscillation of temperature. This being the theory, I sought to test it by twice integrating an expression for the observed law of pressure change.



Thinking to diminish the disturbing effect of local conditions, I combined for my test observations made at San Francisco and Girard College. To avoid complication from the annual variation in the character of the diurnal oscillation, I used only the observations for the equinoctial months of March and September. Making the combination and giving it graphic expression, there resulted the curve shown in figure 6. This curve I undertook to integrate, and wishing to avoid the labor of converting it into an equation, I devised a graphic method of performing the operation. It is evident that, regarding the curve as an equation, the area contained between any two of its ordinates is the definite integral beween the limiting values represented by the corresponding abscissas. On cross section paper it is easy to estimate such an area by the counting of squares. Selecting twenty-four equidistant ordinates I ascertained the definite integrals contained between the first of these and each of the others severally, and this gave me twenty-four equidistant values of the integrated function. Assuming an arbitrary scale, I platted them as the ordinates of the integrated curve, obtaining figure 7 as the result. A repetition of the process produced the curve in figure 8, which, if the theory was correct, should express the diurnal variation of the temperature of the atmosphere. It has the general form of a temperature curve, but its maximum is several hours later than the maxima shown by the observations at San Francisco and Philadelphia.

This difference appeared to be susceptible of explanation, for the part of the atmosphere heated most rapidly is that in contact with the earth, and in the later part of the day the lower strata become so much warmer than the upper that a vertical circulation is produced, whereby cooler air is brought down and the rise of temperature near the ground somewhat checked. Thermometric observations near the ground therefore fail to exhibit the variations in the amount of heat contained in the atmospheric column as a whole.

To escape this difficulty I tried to discover the temperature of the air column as a joint function of insolation and radiation. Radiation to space was assumed to be at a constant rate. The rate of heating by the sun was assumed to be proportional to the sine of the angular height of the sun above the horizon. On these postulates the law of temperature increment for the equinoctial day in the latitude of Philadelphia is expressed by the curve in figure 9. Integrating this, I obtained as the diurnal law of temperature variation the curve in figure 10. This curve resembles very closely the one obtained from the curve of barometric oscillation (8), differing by less than an hour in the epochs of maximum and minimum. The theoretic curve of temperature increment (9) moreover possesses a general resemblance to that derived by one integration from the barometric curve (7).

If no other test had been possible, I should have regarded the hypothesis as well sustained, but unfortunately for it there are widely different types of barometric oscillation in different parts of the world, and when the same integration was applied to curves of other types, the results were found to have little or no resemblance to temperature curves. I was compelled therefore to believe that either the theory or the method of testing it was inadequate; and I may add that I have since satisfied myself by independent reasoning that the relation of the temperature oscillation to the pressure oscillation is less simple than the one suggested by Espy.

I have pursued the subject farther than was warranted by its use in illustration of graphic method, and I have done this for the sake of a moral, with which I will close. The sun is the creator of the day. By alternately giving and withholding his light and heat he brings to pass an infinite series of events which agree in having a diurnal period of wax and wane. Were we to ascertain the quantitative elements in these cycles of events, and picture them by curves, it is to be anticipated that these curves, representing as they would a series of functions of the same periodic flux, would include a large number of close coincidences. For this reason the test I applied, though by no means a waste of energy, could not by itself

demonstrate the assumed dependence of pressure on temperature. The pressure and temperature cycles, belonging both to the diurnal family of the sun, might perhaps trace their relationship to their common ancestor through separate lines of descent and neither acknowledge the other as parent. It is unsafe to infer because two currents have a common rhythm that one has borrowed it from the other; it is always possible that they flow by independent courses from a common source.

ART. XLVI.—*Geology of the Rainy Lake Region, with remarks on the classification of the Crystalline Rocks west of Lake Superior. Preliminary note;* by ANDREW C. LAWSON.

IN the Rainy Lake Region there can be distinguished five groups of rock formations which are geologically distinct from one another. The petrographical characters of each group are peculiar to itself to a great degree; so that a scheme of classification which takes into account only those conditions of mutual relationship, as observed in the field, that serve to distinguish the different groups with respect to their stratigraphical position, age and genesis is at the same time probably the best that could be adopted for considering systematically the purely petrographical characters of the rocks of this field by laboratory methods. The rocks comprised in the first of these groups may be arranged in the following scheme in which Rosenbusch's nomenclature is employed for the non-foliated varieties. With regard to the foliated varieties it will be observed that the word "gneiss" is used simply with reference to the structure of the rock independently of its mineral composition.

Type.	Non-Foliated.	Foliated.	Texture.
Granite, (quartzose).	True granite. Granitite. Amphibole Granite.	Granite-gneiss. Amphibole-granite-gneiss.	Medium grained, or fine grained.
Syenite. (quartz absent or only sparingly present).	Hornblende syenite.	Hornblende-syenite-gneiss.	Usually very coarse grained and in micaceous varieties of porphyritic aspect.
	Mica syenite.	Mica-syenite-gneiss.	
	Augite syenite.	Augite-syenite-gneiss.	

The rocks classified thus under two main types, the granitic and the syenitic, cannot as yet be separated in the field in such a way as to afford a definite suggestion as to their mutual geological relations. Geographically it is frequently possible to map off the quartzose, usually finer grained: rocks included in the two parallel series of the granitic type from the very slightly quartzose, coarse-grained members of the syenitic

type. But what this geographical separation means, whether the one is earlier or later than, above or below, the other, or what other geognostical relation exists between them, either in space or in time, the meagre amount of field work that has yet been done, relatively to the magnitude of the units with which we have to deal, leaves still an unsettled question. Such feeble suggestions of possible relations as have been received will be set forth in another place.

The granites and the foliated rocks of similar composition and habit, which are classed with them in parallel series, are genetically the same, the latter owing their distinctive characters to a differentiation in structure due to the influence of certain conditions affecting portions of a more or less homogeneous magmatic mass at the time of its solidification. The field evidence establishing the common genesis of the granite and gneiss is so strong that there is no room for doubt in the matter to one who has carefully studied their occurrence in nature. It is of course possible for geologists who are wedded to extreme metamorphic views to regard these rocks, even granting their sometime magmatic condition, as fused sedimentary strata; and they are at perfect liberty to do so, but so far as evidence goes the supposition is purely gratuitous and cannot in the absence of facts to support it be entertainted as a very probable hypothesis. The evidence in favor of such a supposition is, so far as can be gathered from a study of the region under consideration, very speculative. What is said of the granites and granite gneisses is also true of the syenites and their foliated varieties. The identity and igneous origin of the foliated and non-foliated series is shown by (1) the direct traceable passage from the granitic to the gneissic phase in a rock mass which must be regarded as a geological unit; (2) by the identical nature of their contact relations to other series of rocks to be mentioned, viz: the igneous, brecciated nature of the contact, the gneiss or granite holding angular fragments of the rock through which it breaks, and sending apophyses into it, which, where the rock is gneissic are often distinctly foliated; (3) the identity, as revealed by the microscope, of the mineral composition and structure of two varieties of the same mass.

This group of crystalline rocks, granites and syenites, foliated and non-foliated, forms the floor of the region upon which rest all other formations that are not in the condition of dykes or intrusive bosses. Regarded as a geological system of rocks it occupies an apparently paradoxical and anomalous place in any scheme of classification. As the floor or basis upon which the geological column of stratiform rocks rests it must be regarded as the first or fundamental system of rocks of which

we have any cognizance. If, however, we inquire as to the age of these rocks we are forced by the direct application of the simplest principles of geological science to look upon them as of later age than certain of the series which overlie them. We do not yet know their original condition prior to the fusion from which they solidified into granites, syenites and gneisses. They may have been sedimentary; they may have been the original crust of the earth. The abstract speculations that are so often indulged in on this and similar questions have not decided the facts of the matter. There is as yet no sufficient ground for a just opinion upon it. But whatever may have been that original condition the evidence is clear on this point, viz: that the fusion and solidification, whereby they were brought into their present condition as firm crystalline rocks, took place at a period subsequent to the existence, in a hard, brittle condition, of the stratiform and often very distinctly clastic rocks which occupy a higher place in the column. Therefore, as rocks, the members of this fundamental system are of younger age than that of the nearest overlying formations. An analogous case with which every geologist is familiar is that of dykes. These are of younger age than the strata they cut, although the main mass, of which they are merely the apophyses, is far inferior to those strata and may form the base upon which they rest. These apparently paradoxical but naturally quite consistent attributes of absolute inferiority of position with reference to all observable stratiform systems or series, and an age younger than part of the latter, places a classification of these Archæan formations based on age at variance with that which has reference to stratigraphical position. This is not usual in geology, except in the case of intrusive sheets of trap, and raises the question of which method should be adopted. The classification according to age is the usual one, but although this is facilitated in the post-Archæan formations by a knowledge of the laws governing the distribution in time of organic forms, it is primarily based upon the relative position of strata. The most prominent idea associated with these granites and syenites and their gneissic modifications is their basal or fundamental relation to all stratiform rocks. The formations of the region are, therefore, considered in their natural ascending order, in so far as they are stratiform, while dykes and intrusive bosses are taken in order of their age.

The group of rocks comprised in the table given above is designated geologically as the Laurentian System in accordance with the practice in vogue among geologists of so naming the lowest well-defined system of crystalline rocks which is clearly separable from overlying strata. It is not intended by

the use of this term to imply that the rocks are necessarily of the same age as those described as the typical Laurentian by Logan, or as those named Laurentian in any other part of the world. For it is manifestly at variance with scientific methods to definitely correlate, with reference to age, rocks in which there are no criteria for comparison other than their petrographical characters. That the rocks considered have passed through a period of fusion and solidification is a palpable fact in the Rainy Lake Region, and will probably be also established beyond question in other regions when they come to be carefully studied.*

But to assume that the period of solidification, which defines the age of the rock, was the same the world over, is as yet unwarranted. If prior to fusion the material was in form of stratiform sediments, these may have been of many different ages, and may have been fused in different parts of the earth at very diverse periods anterior to the deposition of fossiliferous strata. If it constituted, prior to fusion, the first formed crust of the globe, the period of fusion might, as before, be very different in different regions before the advent of life upon the surface of the earth. The loose way in which the term Laurentian is used is convenient in the present state of science, but let it be clearly understood—as it is not generally—that the usage is different from that familiar in the fossiliferous formations. It is in this loose sense—the strictest permissible in the present state of science—that these rocks are referred to the Laurentian.

Superimposed upon the rocks thus referred to the Laurentian system, the splendid exposures of the shores of Rainy Lake reveal as the next geological group a thick series of very distinctly stratiform mica schists and fine grained, gray, evenly bedded, often garnetiferous, very quartzose granulitic-gneisses. The use of the same term "gneiss" both for the foliated modifications of granites and syenites which are clearly of igneous origin, and for bedded rocks of similar composition to the granites, but whose natural history has evidently been very different, is very confusing. The lack of distinction in terms has been fruitful of much error. The term gneiss is coming more and more to be used by geologists to describe a certain phase of structure independent of composition. The fine-grained bedded gneisses often have the character of granulites when exam-

* Wadsworth has already called attention to the fact that the foliated granite of the Marquette district, described by Brooks and other geologists as Laurentian, is of more recent age than the rocks there referred to the Huronian and the intrusive nature of the contact is described. Vide Notes on the Geology of the Iron and Copper Districts of Lake Superior, Bull. Mus. Comp. Zöol., Harvard, 1880, p. 52 et seq., p. 70 et seq. The work was not known to me when I described the Contact of the Laurentian and Keewatin of the Lake of the Woods, Annual Report, Geol. Survey of Canada, 1885.

ined under the microscope, and the term "granulite-gneiss" might be useful as a distinguishing term if the granulitic character can by more extensive study be shown to be a common one. For the present it will be used provisionally as one that suggests the contrast that exists between them and the granite-gneisses.

This thick series of mica schists and granulitic gneisses attains its greatest development so far as has yet been observed in the southern part of Rainy Lake, where its thickness in continuous exposure, with the strata at low angles which preclude the idea of reversed dips, can be measured for a thickness of over two miles in a low anticlinal. The series is for convenience designated the Coutchiching series, from the Coutchiching Rapids at the head of Rainy River where the rocks are first met with on entering Rainy Lake from the west. They are very sharply and distinctly marked off from the lower granites and gneisses of the Laurentian. The geological contact between the Coutchiching series and the Laurentian system is one of neither conformity nor unconformity. The break is of an entirely different order, and the contact is eminently that of an igneous injection or intrusion of the lower through the upper rocks. This series appears to thin out rapidly toward the north, and on the north shores of the southern part of Rainy Lake, in the neighborhood of Seine, Swell, Red-gut and Rocky Islet Bays, and on the islands of the lake, it is seen to form a trough in which lies folded another higher series of entirely different characters. The rocks comprising it are for the most part of volcanic origin. They are chiefly black-green, compact, hornblende schists; softer, less compact, and more fissile green schists in which hornblende is the prevailing constituent, but with chlorite, calcite, epidote and other decomposition minerals well represented in them; and, in intimate association with these schists and interbedded with them, great sheets of 'trap' comprising uralitic diabases and gabbros (often called diorites) and other massive altered basic volcanic rocks of less determinate characters. These altered traps are sometimes quite massive and sometimes schistose to a varying extent, in which case the crushed or stretched condition of the rock is so clearly displayed in microscopic sections as to leave no doubt that the schistosity is due to pressure and to stretching or pulling forces upon the rock after the assumption of a firm crystalline condition. When the crushing has been excessive the original character is often almost or completely obliterated, particularly as the comminution of the rock under such forces is accompanied by the development of secondary minerals like quartz, calcite, epidote, zoisite, chlorite and albite. Included also in this series are dark green, very fissile glossy schists

holding water-worn pebbles; green volcanic breccias; finer textured clastic rocks or 'graywackes'; sericitic schistose quartz-porphyries and regular porphyroids; and soft, fissile, nearly always much decomposed hydromicaceous schists with which are associated yellowish dolomitic segregations.

The breccias, graywackes and hydromica schists are more commonly met with in the northern part of the Rainy Lake Region than on Rainy Lake itself. This group of rocks is the same as a large portion of the series described in my report on the Lake of the Woods Region as the Keewatin series, and in the northern part of the Rainy Lake Region can be traced in direct continuity with that series. They will therefore be referred to as the Keewatin series of rocks. Concerning the geological relations of the Coutchiching and Keewatin series it is not possible to make any sweeping statement as to their conformity or unconformity. The Coutchiching rocks do not appear to have been at all disturbed prior to the deposition of the Keewatin, and the parallelism of the strike and dip of the strata or beds of the two series is often seen to be perfect. But as Geikie points out the geological conformity or unconformity of two sets of strata implies a broader question than the mere relations in space of their contiguous portions. Strata which are in close contact and show at certain places perfect parallelism may sometimes be separated by ages. The appearance of parallelism is often simulated by pressure and folding so that it is not always a criterion of continuity of geological history. The very diverse character of the two series, the Coutchiching and the Keewatin, is proof of a profound alteration in the conditions of rock formation, which implies a geological break, though it does not indicate its duration. The Coutchiching series is seen occasionally to be cut by intrusions of a certain character which have not been detected traversing the Keewatin rocks. These may possibly be instances of vents from which the traps of the Keewatin series were extravasated. In the northern part of the Rainy Lake Region the Keewatin series comes into direct contact with the Laurentian without the intervention of the Coutchiching series, and the conditions of contact are those which have been described as obtaining in the Lake of the Woods Region. The contact of the hornblende schists and altered traps with the Laurentian rocks is of the same igneous or brecciated character as that observed on the Rainy Lake between the Coutchiching and the Laurentian, the direct inference being, of course, that the Laurentian rocks are of more recent age as such than either the Coutchiching or Keewatin, although stratigraphically they are inferior to both.

Of later age than Laurentian, Keewatin or Coutchiching is a system of dykes and bosses of red granite, in which there has

never been detected the slightest tendency to gneissic foliation. This granite is found cutting the Laurentian gneiss in sharply defined but irregular dykes in certain parts of the region, particularly in the Northwest Bay of Rainy Lake. These dykes are very frequently associated with "veins" of pegmatite. Where exposures are few and isolated there is danger of confusing these granites with the older granites of the Laurentian; where the country is well uncovered, however, the different relationships of the two are quite apparent.

Of still later age is a system of strong, well-defined dykes of diabase cutting the Laurentian, Coutchiching and Keewatin rocks and the post-Laurentian granites. These, wherever observed in various parts of the region have a strike of N.W. to N.N.W. Their width is generally from 60 to 150 ft., and they are sometimes traceable for miles. These dykes have been studied microscopically, as have all the chief types of rocks occurring throughout the region, and some interesting features have been brought to light concerning them which will be found described elsewhere. Besides these dykes there occurs between Seine River and Turtle Lake, east of Rainy Lake, a somewhat extensive mass or boss of very coarse grained saussurite gabbro, concerning the age of which it is only known that it cuts the Keewatin rocks, and is therefore younger than them. It is not improbable that it is of synchronous origin with the diabase dykes, possibly the plutonic facies of the same rock. These later diabases and gabbro have an interesting possible or problematic relationship to the trap flows which form so large a part of the Animikie and Keweenawan series.

The rocks of the region or their equivalents appear in their eastward geographical distribution in the neighborhood of Lake Superior to pass in a folded state under the flat lying beds of the Animikie series, the contact being one of marked unconformity. The Animikie is, according to the prolonged and valuable researches of Prof. R. D. Irving, of the United States Geological Survey, the geological equivalent of the typical Huronian of Logan.* The Animikie or Huronian is, according to the same eminent authority,† distinct from and underlies the Keweenawan (Nipigon). Hence the classification of the various geological systems or series of rocks in the country west of Lake Superior, so far as our present knowledge goes, is with reference to their place in the ideal geological column, as follows:

Keweenawan (Nipigon).
Huronian (Animikie).
Keewatin.

* Monograph V, United States Geol. Survey, pp. 367–386, p. 390.
† Op. cit., pp. ibid.

Coutchiching.
Laurentian.

With reference to their age, as follows:

Keweenawan (Nipigon).
Huronian (Animikie).
Diabase dykes and gabbro.
Granite, post-Laurentian.
Laurentian.
Keewatin.
Coutchiching.

Petrographical Laboratory, Johns Hopkins University, March, 1887.

ART. XLVII.—*Identity of the Photosalts of Silver with the Material of the Latent Photographic Image;* by M. CAREY LEA, Philadelphia.

IN the first part of this paper I described certain strongly colored forms of silver chloride, bromide and iodide, obtained independently of any action of light, for which I proposed the name of photosalts, by reason of their identity with the products of the action of light on the normal silver haloids; both with the substance of the latent image itself and also with the principal results of the continued action of light on these haloids. It remains to prove this identity.

First as to identity with the product of the continued action of light.

If we expose silver chloride precipitated with excess of HCl to light, we get a deep purple black substance which boiled with dilute nitric acid gives up a little silver, at the same time somewhat lightening in color and forming a dull purple material which closely resembles some of the forms of photochloride described in the first part of this paper, most those produced by the action of sodic hypochlorite or of ferric chloride on metallic silver: it shows the same reactions with ammonia that they do. The brighter colored photochlorides are not formed by the action of light on silver chloride.

But these brighter colored chlorides can also be shown to be formed through the action of light. Most salts of silver darken by exposure, and when these dark products are treated, first with HCl, and then after thorough washing, are boiled with dilute nitric acid, we can obtain results perhaps as varied as those which I described in the former part of this paper as arising from purely chemical action.

Silver oxalate exposed for two days to sunshine, covered with water and with frequent agitation, changed to a deep brownish

black which by treatment with HCl became a little lighter. When this product was washed and boiled with strong nitric acid, it acquired a fine deep copper red color, the acid taking up silver. This red substance dissolved in ammonia readily, leaving a small amount of black residue; the same with sodium hyposulphite.

(This examination, made a year ago, has recently been repeated with a view to obtaining a quantitative determination of the proportion of Ag_2Cl contained in the red product. The exposure was for about a day, the oxalate at the end of the exposure seemed absolutely black. After treatment with HCl it assumed a purple black shade. After thorough washing and boiling with dilute nitric acid, which removed a large quantity of silver, perhaps 12 or 15 per cent of the entire quantity, it had a fine lilac purple color. Analysis showed that it contained about one-half of one per cent of subchloride, or more exactly, 0·45 per cent Ag_2Cl was found).

The red chloride thus obtained from silver oxalate, not only closely resembles the red chloride obtained by means exclusively chemical, but shows the same behavior to reagents.

Treated with ammonia it dissolves leaving a black residue. The formation of this residue takes place precisely in the same manner with both substances. As fast as the material dissolves the liquid becomes clouded and an extremely fine black substance seems to form within it, which gradually falls to the bottom.

Treated with solutions of the alkaline haloids, the red chloride derived from exposed silver oxalate remains unchanged after 24 hours contact with potassic chloride and becomes paler and more lilac under potassic bromide; under potassic iodide becomes gray. These reactions correspond with those of the photochloride.

Silver phosphate belongs to the more sensitive silver salts and easily darkens in sunlight. In a few hours it becomes greenish all through, after which further exposure produces little visible effect. This product becomes with HCl quickly gray, and by treatment with nitric acid after washing, light pink.

Silver tartrate by exposure to sun became quite black. With HCl this changed to reddish gray or dull pink. This product well washed and let stand with cold nitric acid 1·36 became first lavender and then light pink.

Silver carbonate by prolonged exposure became greenish black, and with the above treatment yielded a dull pink photochloride.

Silver pyrophosphate even by several days' exposure to winter sun did not blacken, but assumed an ochreous or buff shade. With HCl this passed to a sort of salmon pink and by heating

a few minutes with dilute nitric acid, to a beautiful copper shade.

Silver acetate was singularly little affected by sunlight, it looked blackish, but on closer inspection was found to be very little altered. By the same treatment as above it yielded a pale pink photochloride.

So far as examined, all silver salts thus treated yielded pink or red photochloride.

These facts may serve to show the identity of the photochloride with the principal product of the continued action of light on silver chloride and on other salts of silver, subsequently converted into chloride. I should wish, however, to use this word identity in a somewhat limited sense. When the photochlorides are formed by different methods without the aid of light hardly any two forms can be considered absolutely identical: they differ in color and in proportion of subchloride, as already often mentioned, but they also differ in other respects, especially in resistance to reagents. Some forms are far more easily destroyed by nitric acid: those obtained by the action of sodium hypophosphite (as presently to be described) are amongst the most easily destroyed by nitric acid. There is variation, too, in the degree of their resistance to ammonia.

Very similar differences are found in the stability of the photochlorides obtained by the action of light: some are much more readily attacked by nitric acid than others. The product obtained by the action of light on silver chloride resists ammonia more strongly than that obtained by the action of HCl on exposed silver oxalate. This last is quickly attacked. Generally, I think the dark colored forms are the most stable.

At a future time it may perhaps be possible to distinguish more exactly between these varieties.

I next pass to the consideration of the identity existing between the photosalts and the material of the latent image. Before entering, however, on that matter, it is necessary to describe a reaction leading to the formation of these photosalts, somewhat differing from the reactions already mentioned, and which has important bearing on the subject.

The remarkable action which an alkaline hypophosphite exerts on salts of copper was described many years ago by M. Wurtz. Its action on silver salts, though there is no parallelism between the two, has enabled me to find a key to some of the great difficulties of the latent image.

A dilute solution of sodium hypophosphite if poured over a mass of chloride, bromide or iodide of silver formed in the absence of light, produces no visible effect, but has the property of bringing those substances into the condition in which they

exist in the latent image. Applied in strong solution and with the aid of heat, it produces brown purple photochloride, bromide and iodide of silver. I will here briefly describe the first of these compounds in order to continue the series of photochlorides, and then pass to the consideration of the latent image.

Photochloride of Silver by Sodium Hypophosphite.

Silver chloride freshly precipitated with excess of HCl and well washed, placed in a flask with a strong solution of sodium hypophosphite and heat applied begins to darken before the boiling point is reached. Actual boiling for ten or fifteen minutes gives a deep chocolate color. This product well washed and freed from traces of metallic silver by cautious boiling with very dilute nitric acid has a pink, red or brown color varying in intensity according to the length of the action. Sometimes a lavender shade is produced, and this is more apt to be the case when the silver chloride has been precipitated with excess of silver nitrate instead of excess of HCl.

Silver determinations of two specimens of the purified product were made, indicating the presence in one specimen of 1·77 per cent of subchloride, in the other of 3·53.

By the continued action of heat for many hours a complete reduction to metallic silver takes place.

Photochloride obtained in this way has generally a brown or dull purple color. Boiled with nitric acid it is apt to break up in as many minutes as some other forms would require hours for decomposition, yielding white chloride, whilst the nitric acid takes up small quantities of silver.

Identity of Photosalts with the Material of the Latent Image.

It is proposed here to show:

1st. That in the entire absence of light, sodium hypophosphite is able to affect a sensitive film of silver haloid exactly in the same way as does light, *producing a result equivalent to a latent image formed by light* and capable of development in the same way as an actual impression of light.

2d. That these two effects, the impression produced by hypophosphite and that by light, comport themselves to reagents exactly the same way and seem every way identical.

3d. That the image produced by hypophosphite on silver chloride always gives rise to a positive development, but on silver bromide may give rise either to a direct or to a reverse image, *both of these effects corresponding exactly with those of light.* More than this, sodium hypophosphite may be made to reverse the image produced by light on silver bromide and conversely

light may be made to reverse the action of hypophosphite. So exact a correspondence in these remarkable properties can scarcely be fortuitous.

I.

A silver haloid formed in the absence of light and subjected to the action of sodium hypophosphite gives rise to the gradual formation of subsalt, which combines with the normal salt in the manner described in the previous part of this paper. This action of the hypophosphite closely corresponds with that of light. In its initial stages it is invisible, but can be brought out, in both cases by development.

If we form a film of chloride, bromide or iodide of silver and with a glass rod dipped in solution of hypophosphite, make marks upon it, these marks can with the utmost ease be developed in precisely the same way as an image produced by exposure to light.

A very simple mode of operating consists in imbibing photographic paper with a solution of an alkaline haloid, drying, applying a silver solution and then thoroughly washing, all of course with careful exclusion of active light. If the silver solution is acidulated with nitric acid, a drop to the ounce, the result is brighter, but this is not important. In any case the washing must be thorough.

Marks made on this paper can be developed with the oxalate developer with the utmost facility. If a strong solution of hypophosphite is applied cold, it may be washed off at the end of a minute, but a stronger impression is obtained by allowing it to wait a half an hour before developing. Or the action may be accelerated and increased in strength by laying the freshly marked paper on a hot surface, or better, by steaming it, before applying the developer. A convenient mode of steaming is to lay two pieces of glass on a small water bath kept boiling, with a space between them. Over this space the paper is rested for two or three minutes. Paper prepared with a solution of KCl, KBr, or KI, dried and floated on acidulated solution of silver nitrate and well washed, if marked with strong solution of hypophosphite and steamed for two or three minutes, will develop the marks as black as ink on a white ground. The use of heat simply gives a blacker development, but a very vigorous image may be got without.

(A similar result may be obtained by substituting for the hypophosphite a dilute solution of potash and an oxidable organic substance. With milk sugar the action is very energetic and heat is quite superfluous).

Both these are the initial steps of reactions which when prolonged result in the visible formation of the colored photosalts.

It is a matter of interest that sodium hypophosphite which produces the above described effects, has no developing power whatever.

II.

The two impressions, that formed by light and that by hypophosphite, are similarly affected by reagents

As an example of this identity of effect produced on the two impressions, I first take the action of nitric acid.

Chloride, bromide and iodide papers were exposed to moderate diffuse light under a screen with openings, for a proper time to form a latent image, the chloride and bromide for four or five seconds, the iodide for twenty or twenty-five. They were then cut into halves and one half of each was soaked in strong nitric acid for five minutes. These halves were then washed for some hours and were developed along with the halves not so treated. Result was, latent image on silver chloride almost if not quite uninjured; on silver bromide, somewhat affected but still strong; on silver iodide entirely destroyed.

Similar portions of the same papers were then marked with hypophosphite and were cut into halves and one-half was subjected to the action of nitric acid in exactly the same way as the previous. The result was exactly as before. The hypophosphite marks on the half of the chloride paper that had been treated with acid came out in development as vigorously as on the half that had not been treated. The bromide paper showed the marks weakened by the acid but still strong; on the iodide not a trace appeared. In all respects the result was the same, what the one resisted, the other resisted, what destroyed the one destroyed the other.

Another confirmation is presented by the action of the alkaline haloids upon the latent image.

The latent images produced by light on chloride, bromide and iodide of silver were all treated with cold and moderately strong solutions of potassic chloride, bromide and iodide for half an hour, and were then subjected to development. It was found that all three silver salts bore the action of potassic chloride and bromide fairly well, the images were somewhat weakened but strong developments were obtained without difficulty. But when potassic iodide was applied the latent image was totally destroyed.

The visible effect of the alkaline haloids on the photosalts exactly corresponds with their action on the latent image. Potassic chloride and bromide, applied in moderately strong solution and cold have little effect, but potassic iodide quickly destroys them.

Therefore the action as well of nitric acid as of KCl, KBr and

KI is exactly the same on the latent image impressed by light on AgCl, AgBr and AgI as it is on the corresponding photosalts.

III.

The impressions produced by alkaline hypophosphite upon silver chloride always give rise to direct images, darker than the ground on which they are formed. The same substance produces an impression on silver bromide which may by development produce either a direct or a reverse image. So that there is a perfect parallelism with the action of light.

The reverse action of light, sometimes called solarization, shows itself as follows. A film of bromide being exposed to light, part covered by an opaque screen, the exposed portion receives an impression capable of development, and this impression grows in strength to a certain point, then recedes and reaches a condition in which it is less susceptible of development than before exposure. All bromide films, even unexposed to light, will darken in a developing solution in time. The portion that under the action of light has reached the reverse stage resists the reducing action of the developer better than that which was not exposed at all, and consequently appears after development as light on a dark ground and is therefore a reverse image. As to the cause of this action we are as yet wholly in the dark. If the continued effect of light was simply to restore the affected part to its original state we might attempt an explanation by affirming that the continued action of light undid its own work. But the fact of the resistance to reduction being greater than before exposure shows that some as yet unknown action of light is in play. The reverse action cannot be due to oxidation as has been suggested, because hypophosphite reverses and certainly cannot oxidize.

The reversing action of light on silver bromide finds its counterpart in the action of sodium hypophosphite.

If we take bromide paper (it is immaterial whether in making it the bromide or the silver solution be applied first, but for these experiments on the reversal of the image it is essential that a pure neutral silver solution be employed and that after the second solution has been applied the paper should be thoroughly washed, all the operations being of course performed by inactive light):—if we take such paper and make marks on it with a strong solution of hypophosphite, and then throw the paper into potassio-ferrous oxalate, we shall get a direct development; the marks will be stronger than the ground. If now we continually weaken the hypophosphite solution, we shall presently reach a point at which these marks are in development almost wholly indistinguishable from the

ground on which they were made. But continuing the dilution still further we presently reach a point at which the marks reappear, but this time reversely; as lighter marks on a darker ground. This result is obtained with about a two per cent solution; the first mentioned effect comes with a solution of 25 or 30 per cent. So that according as we use the hypophosphite solution stronger or weaker we obtain exactly opposite effects. Here the parallelism is striking but not perfect, at least it remains to be explained why the action in the two cases proceeds in a reverse order. All the other reactions show a perfect identity.

Time will also sometimes produce the same effect as dilution. Paper marked and put away for 24 or 48 hours, giving at first a direct image may after that time give a reverse one. This effect is extremely uncertain and I think, exceptional. I have kept very many pieces for periods from a few hours to several weeks, which first and last gave direct images only; a few became reversed. But the experiment itself, the opposite effect of strong and weak solutions, is liable to no such uncertainty.

Again, we may make light and hypophosphite interact and each reverse the other's action.

To make hypophosphite reverse the action of light, I take a piece of silver bromide paper, expose it to the action of diffuse daylight for a few seconds, then taking it to the dark room, make marks upon it with a glass rod dipped in solution of hypophosphite. On developing with potassio-ferrous oxalate the marks appear lighter than the ground. Or what is perhaps more striking, we take two pieces of such paper, retain one in the dark room and expose the other from 5 to 20 seconds to diffuse light, then make marks on both with a glass rod dipped in strong solution of hypophosphite, and then, after allowing a few minutes for the hypophosphite to act, place them both in a solution of potassio-ferrous oxalate. The marks will develop, in the one case, as dark on a light ground, in the other (that exposed to daylight) as light on a dark ground.

We have here made the hypophosphite imitate the action of light: it has reversed the image in the same way as would result from a prolonged exposure to light. It will next be shown that light may be made to imitate the action of hypophosphite and reverse the effect already produced by that or other reducing agent.

If we take the red or purple silver bromide, preparing it with exclusion of light and the same precaution as in the case of a dry plate and extend it over paper (it is best though not essential, to mix it with a little gelatine to enable it to retain its hold on the paper in the subsequent treatment) dry it and

expose it to light under a screen such as a piece of opaque stiff pasteboard with openings cut in it: then apply potassio-ferrous oxalate, we shall obtain a very remarkable effect: all the parts exposed to light take a reversed development and appear as lighter spaces on a dark ground. And this goes so far that we may expose till we get a visible and quite strong image, darker than the ground and yet in development this darker portion will come out lighter than the ground. Indeed I have one specimen which shows almost white figures on an intensely black ground. Before development these light figures were brown, by exposure to light, on a rose-purple ground. I have seen few more curious results than this.

From the foregoing it follows that red bromide, notwithstanding its intense coloration is in the same condition respecting light as normal silver bromide that has received an impression of light so strong that any further influence of light would cause reverse action, only that a vastly larger proportion of its molecules are affected. In the case of the latent image formed by light on normal bromide it would seem that the particles affected, although numerous enough to serve as a basis of development are still too few and too scattered to be visible or affect the color. The photobromide on the contrary has its mass made up of them. Then if exposed to light, the light carries them a stage farther—brings them to the reverse or "solarized" condition and the parts affected by light develop less strongly than those not exposed.

So light can act the part of hypophosphite and hypophosphite that of light, interchangeably; each can produce a direct action, each a reverse and each can reverse the other.

It then appears that in all the numerous ways in which it is possible to compare the photosalts with the material of the latent image they are found to be identical. The proofs based on development generally, and especially on the reversal of the latent image seem very strong and these receive additional support from the exact identity of reactions shown by the photosalts and by the material of the latent image.

The question of the identity of the photosalts with the products of light on the silver haloids might perhaps be left with some confidence to the cumulative proofs here offered. But I hope to be prepared to give in the next number of this Journal additional evidence from a new direction.

Philadelphia, March 21, 1887.

ART. XLVIII.—*On Photobromide and Photoiodide of Silver;* by M. CAREY LEA, Philadelphia.

Photobromide of Silver.

THIS substance is formed for the most part by the same reactions as the corresponding chlorine salt.

It is not however to be supposed that all reddish-brown substances resulting from the action of reducing agents on silver bromide are the photosalt. By reduction, AgBr may yield a brownish colored form of silver, which, mixed with unreduced AgBr may form a substance resembling the photosalt, but having none of its properties. The two are easily distinguished by the action of cold nitric acid which added to a brown mixture of AgBr and Ag quickly dissolves the silver leaving AgBr. On the photosalt it has no action.

A beautiful variety of photobromide is easily obtained by dissolving silver nitrate in ammonia and adding it to ferrous sulphate previously mixed with solution of soda. Then KBr is added dissolved in dilute sulphuric acid, until the mixture has a strong acid reaction.

Sometimes this method gives immediately a fine purple, sometimes a brown product. But in either case, after washing and cautiously heating with dilute nitric acid, a beautiful purple results. Much care is needed in the nitric acid treatment or particles of yellow bromide will form.

A specimen obtained in this way gave figures indicating 7·25 per cent of subbromide. Each specimen however varies in composition, often very materially.

I subsequently found it desirable in some degree to vary the method and to determine the best proportions in which the materials were used, to obtain a constant product. That which I prefer to use is as follows:

Six grams of silver nitrate are to be dissolved in 200 centimeters cube of water and ammonia added until the precipitated oxide re-dissolves easily. Twelve grams of ferrous sulphate are dissolved in 200 c. c. of water and the silver solution is poured into this. Then four grams pure caustic soda dissolved in 50 c. c. of water are added, let stand a few minutes, then five grams of KBr dissolved in a little water. Finally, dilute sulphuric acid until the whole has a strong acid reaction.

This product, well washed and then heated cautiously with nitric acid 1·36 diluted with five times its bulk of water, gives photobromide of a shade of royal purple, extremely beautiful.

Notwithstanding its fine color it proved to contain but little subbromide, not quite one per cent (0·98 p. c.).

Various other methods may be employed. Silver bromide

may be dissolved in ammonia and be treated first with ferrous sulphate and then with dilute sulphuric acid. This method, which is very good with the chloride, is less available for the bromide because of the less solubility of the normal bromide in ammonia, so that although the product is good it is small in quantity.

Very good results are obtained by dissolving silver phosphate, nitrate and probably almost any other salt of silver in ammonia, adding ferrous sulphate and after two or three minutes, hydrobromic acid.

Potash bromide and cupric sulphate may be made to act on metallic silver in fine powder, but the product is contaminated with much copper, difficult to get rid of.

When AgBr is treated with sodium hypophosphite a brown or brownish purple form of photobromide is obtained which seems to be more easily decomposed by nitric acid than most other forms of this substance.

Potash or soda with oxidable organic substances, made to react on silver nitrate and then treated with HBr gives the photobromide. With soda and milk sugar or aldehyde a rose-colored or pink product is generally obtained.

Reactions.—In strong solution of potassic iodide it dissolves and this solution by dilution lets fall pale yellow normal bromide. With a weaker solution it becomes somewhat lighter in color.

With acid ferric sulphate there is no action in the cold, but with a few minutes boiling the photobromide is converted into bright colored normal bromide.

In sodium hyposulphite it dissolves, leaving a little black residue of silver.

With ammonia the action at first seems slower than is the case of the corresponding chloride and if the ammonia is poured over the photobromide in small quantity, it may seem to be without effect. But the photobromide shaken well up in a test tube with a large excess of ammonia is almost instantly blackened.

Exposed to light, the red shades of photobromide darken with great rapidity. Placed along side of the corresponding chloride, the contrast is very striking:—a strong image forms on the bromide long before anything appears on the chloride; nevertheless, if these two films are thrown into a developing solution, the chloride on which nothing could be seen, gives a vigorous positive development, while the bromide which already showed a strong positive image develops a negative one. The details of this reverse development have been already considered in another paper.

As respects the direct effect of light unaided by develop-

ment, the contrast between its action on the normal haloids and on the photosalts is very striking. If a rose-colored photobromide and some normal bromide are exposed side by side the normal bromide (formed in presence of excess of alkaline bromide) darkens but very slowly while the photobromide is quickly acted on. I have seen deep purple photobromide change to brown all over its surface with less than five minutes' exposure to diffuse light in the middle of a room, an amount of exposure which would scarcely have produced a visible effect on normal bromide formed in presence of excess of KBr.

When photobromide is exposed to the spectrum, it shows the same difference in sensitiveness and darkens more rapidly than photochloride. But it gives little indication of color.

When exposed under colored glass photobromide gave distinct indications of reproducing colors, but much less favorably than photochloride. Under green glass it became bluish, under blue greenish, under yellow glass it bleached and under red glass the red of the photobromide remained unchanged.

Photoiodide of Silver.

The most characteristic color of this substance seems to be a fine rich purple. It is obtained in much the same way as the corresponding chloride and bromide, with this limitation, that an excess of alkaline haloid must not be present, as the photoiodide is quickly destroyed by it. The iodine salt differs much more from the bromide than does the bromide from the chloride and two striking distinctions are, its easy decomposition by its own alkaline salt, and its action with ammonia, as will appear beyond.

A very easy and satisfactory method of obtaining the photoiodide is the following: Silver is to be reduced from the nitrate or chloride, in fine powder in any convenient way; I have usually employed Levol's method. To a solution of potash, iodine is to be added until the liquid becomes almost black. This iodine solution is to be diluted and poured over the silver by degrees, keeping the silver constantly agitated, until the whole mass becomes clear bright purple.

Any excess of silver present may be removed by boiling with dilute nitric acid, but this operation requires far more circumspection than in the case of the corresponding chlorine and bromine products. The acid (1·36 was used) must be diluted with twelve or fifteen times its bulk of water, and the boiling must be very short, otherwise the photoiodide is converted into normal yellow iodide.

Another method by which it may be obtained is to add ammonia to silver nitrate in considerable excess and to pour

this into solution of ferrous sulphate. Potassic iodide is dissolved in very dilute sulphuric acid and added till the mixture has a sharp acid reaction. It is necessary to observe that the KI added must be somewhat short of a proportion equivalent to that of the silver. Any excess of silver may be removed in the manner already explained.

Different specimens of the purple product in this way obtained gave various amounts of Ag_2I from 0·64 per cent to 4·63. The same remark made as to the meaning of these determinations in reference to the other haloids, applies to this.

The method of roasting silver oxide until it is black and acting on it with the hydrogen acid of the halogen, which works well in the case of the chloride, does not answer well for the iodide.

When silver iodide is boiled with solution of sodium hypophosphite, it gives a brown product, evidently indicating that reduction to some extent has taken place; the hypophosphite solution may or may not show traces of iodine. The color of the silver iodide may show a very marked darkening, and yet the solution may give no trace of iodine by the most delicate reagents.

This was very difficult to explain until I found that silver iodide has the property of taking up and retaining small portions of iodine, a reaction not very surprising in view of the tendency I have found in silver haloids to take up foreign substances of very various natures, and also of the facility with which iodine is taken up by alkaline iodides. This property in silver iodide was verified by shaking up portions of freshly precipitated and still moist AgI with iodine solutions. Alcoholic solution of iodine diluted until it has a pale sherry wine color is quickly decolorized by AgI, and the same thing happens with a very dilute solution of iodine in KI, which in a few minutes becomes as colorless as water.

This reaction I found particularly interesting, for it not only explained the action of hypophosphite in the case just mentioned, but also gave a clue to the cause of a phenomenon I observed more than twenty years ago, and which then and long afterwards seemed to me an unanswerable argument in favor of the physical nature of the latent image.

At the time referred to I formed films of pure silver iodide entirely isolated from foreign matter, by reducing metallic silver on plates of ground glass, iodizing them with alcoholic solution of iodine, or with Lugol's solution, then washing most thoroughly under a tap for hours. When these films of silver iodide were exposed to light, they received an invisible image which could be developed. But these invisible images, if the plates were laid aside in the dark, had the property of fading

out in a few days or weeks, then could no longer be developed, but the film could receive a fresh image. This seemed an unanswerable proof of the physical nature of the latent image at least on silver iodide. The argument was: If the production of this latent image is the result of chemical action involving the loss of iodine by the silver salt, how then is this iodine recovered when the image fades out? If it is formed of subiodide, where does this latter substance get back its iodine to return to the normal form, as it unquestionably does?

No answer could be given then or after, and this experiment, repeated and confirmed by others, has always seemed the strongest support of the physical theory. When, however, it appears that silver iodide can take up iodine and hold it, the course matters follow becomes evident. By the action of light a very small quantity of subiodide is formed, and combines with the normal to form photoiodide. The iodine set free evidently does not pass off but remains combined with neighboring molecules of AgI, and in the dark gradually re-combines with the photoiodide re-converting it to normal AgI. In this retention the lower tension of iodine as compared with bromine and chlorine no doubt plays its part.

In thus explaining away the fading out of the latent image on silver iodide, the last argument in favor of the physical theory is destroyed, while the chain of proof supporting this new explanation, that the latent image consists of normal haloid combined with its own subsalt, remains unbroken.

Reactions.—When ammonia is poured over purple photoiodide of silver, the color quickly passes to a salmon and then, even after some days, seems to undergo no further change. Of separation of metallic silver as in the case of the corresponding chloride and bromide, there is no trace.

In sodium hyposulphite it dissolves slowly, leaving a slight but distinct residue.

Dilute nitric acid mixed with dilute solution of KI slowly but completely converts it to normal silver iodide.

Light acts slowly upon it, changing the color to greenish-gray.

I have already spoken of the remarkable manner in which light acts reversely by development on photobromide. On photoiodide the effect is usually the same as on photochloride, viz: the action is direct. But occasionally it reverses and the exposed part comes out lighter in development than the part that has not been exposed. In this respect the behavior of the iodine compound is intermediate between that of the chlorine and the bromine.

Note in Conclusion.

The investigations of which the preceding pages are the result, are still unfinished. I have very lately observed the formation of another group of silver haloids quite different from the photosalts. The members of this new group are deeply colored, purple or red, not unlike the photosalts, but are sharply distinguished from them by very different reactions. The photosalts are unaffected by cold strong nitric acid; these new salts are by very dilute acid instantly converted into a pale pink substance which appears to be a photosalt. But the most striking difference is in the action of ferric chloride. A strong solution of this substance shows no action with the photosalts unless left in contact for many hours or days. But these new haloids are instantly converted by it into what is apparently light pink photosalt.

So energetic is this action that a solution of ferric chloride containing one part only to a thousand of water quickly attacks these dark purple salts and decolorizes them. Such a solution might remain indefinitely in contact with the substances I have called photosalts without affecting them.

Other differences exist. So far as I have yet been able to observe these new haloids are formed pure, whereas the photosalts are almost always contaminated with either free silver or free subsalt, or both. As yet there has been no time to fix with exactness their mode of formation or their properties, which I hope to do at a future day.

Philadelphia, April 27, 1887.

ART. XLIX.—*On the Meteoric Iron which fell near Cabin Creek, Johnson County, Arkansas, March 27th, 1886;* by GEORGE F. KUNZ.

THE Johnson County meteoric iron, the tenth whose fall has been observed, is of more than ordinary interest, because its fall is so well substantiated, because it is the second largest mass ever seen to fall, and again because it fell within five months of the date of the 9th* recorded fall, that of the Mazapil. It is

* This Journal, III, vol. xxxiii, p. 221. This meteorite was first mentioned before the New York Mineralogical Club, Feb. 2d, (N. Y. Academy Science, March), and full details will be printed with plates figuring both sides of the iron, natural size, in the Bulletin of the National Museum. The irons whose falls have been recorded thus far, are: Agram, Croatia, May 26th, 1871. Charlotte, Dickson Co., Tenn., Aug. 1st, 1835. Braunau, Bohemia, July 14th, 1847. Tabarz, Saxony, Oct. 18th, 1854. Victoria West, Africa, 1862. Nejed, Central Arabia, Spring of 1865. Nedagolla, India, Jan. 23d, 1870. Rowton, Shropshire, England, April 20, 1876. Mazapil, Mexico, Nov. 27th, 1885.

[It appears questionable whether the 4th, 5th and 6th in the list should be included, since, so far as we are aware, no account of their fall has been published.—EDS.]

almost an exact counterpart of the Hraschina (Agram), Croatia iron, the first of the recorded falls. The Agram iron fell in two fragments, one weighing about 40^{k} and the other about 9^{k}, the combined weight being about equal to that of the Johnson County iron.

This mass fell about six miles east of Cabin Creek, Johnson Co., Arkansas, in longitude 93° 17′ W. of Greenwich, latitude 35° 24′ North, within seventy-five yards of the house of Christopher C. Shandy. Mrs. Shandy states that about three o'clock on the afternoon of the 27th of March, 1886, while in her house she heard a very loud report, which caused the dishes in the closet to rattle and which she described as louder than any thunder she had ever heard. At first she thought it was caused by a bombshell, and ran out of the house in time to see the limbs fall from the tops of a tall pine tree, which, she says, stands about 75 yards from her dwelling. She did not investigate the matter until her husband came home about six o'clock in the evening, when in company with John R. Norton, their hired man, they went out to find the cause of the noise that had so startled Mrs. Shandy. They discovered that a large hole had been made in the ground by some falling object, and that the fresh dirt had been thrown up to a height of thirty feet on the surrounding saplings and trees. They dug down, and a steam or exhalation arose, which on a dark night might perhaps have produced a phosphorescence similar to that described in the case of the Mazapil iron. The iron had buried itself in the ground to the depth of three feet, and the earth around it to the thickness of one inch seemed to be burned.

The ground was still warm when the iron was taken out, and the iron itself was as hot as the men could well handle. The weather had been quite cloudy all day, but no rain fell until night. These facts are from the affidavits of Mr. and Mrs. Shandy and John R. Norton. Mr. Shandy at first supposed that their find was platinum, then silver, and he finally learned what it really was and sold it. Mrs. India Ford, Dr. W. J. Bleck, Mr. S. A. Wright, Constable, and Mr. L. Wright, Chief of Police, also heard the report caused by the fall.

The noise was heard 75 miles away and was likened to a loud report followed by a hissing sound as if hot metal had come in contact with water. It caused a general alarm among the people and teams of horses twenty five miles distant becoming frightened, broke loose and ran away, and in Webb City, Franklin Co., on the south side of the Arkansas river, a number of bells kept on sale in a store, are said to have been caused to tinkle. Cabin Creek is on the north side of the Arkansas river.

Mr. B. Caraway states that he heard two loud reports at Alma, Crawford Co., at 3 o'clock on March 27th, 1886. The

report was also heard at Russellville and in the adjoining county of Pope. The *Democrat* of that place, April 29th, '86, says: "The wonderful meteoric stone as it is called, but erroneously, for nothing is further from stone than it is, is now on exhibition here. We looked on the strange thing and wondered what it was and where it came from. The noise it made when it struck the earth's atmosphere on the 27th of March and came whizzing to earth near Knoxville, will never be forgotten, neither will anyone who looked at it ever forget it." A description of the mass then follows. The *Dardanelle Post* of April 1st, refers to the explosion, and the issue of April 8th suggests the meteorite found as its probable cause. Mr. B. Caraway who visited the spot for me informs me that the pine tree, through which the meteorite fell is 107 feet high, and that the distance from the foot of the tree to the centre of the hole made by the mass is 22 feet 3 inches. The limbs on the west side of the tree were broken, and the meteorite lay in the hole with the flat side down. The hole was 75 yards from the house.

Professor H. A. Newton, who has kindly interested himself in this matter, says that the data furnished indicate that the mass must have fallen nearly from the zenith. This was the direction of the end of its path, the earlier portion being more inclined to the vertical, as the path must be affected by gravity and the resistance of the air. The earlier direction must have been from the N.E. and more nearly from the East than the North.

Mr. Shandy sold the meteorite to Mayor Caraway, who in turn sold it to Col. J. C. Betten,* a lawyer of Eureka Springs, of whom the writer obtained it, Colonel Betten bought it as a business speculation, intending to realize something of an income from its exhibition. While in his possession it was exhibited at Eureka Springs. Circulars headed "The Tenth Wonder" were printed and circulated, notwithstanding the fact that the authors had no knowledge of the number of irons that had been seen to fall and that this was in reality the tenth. It was also called "veritable wonder that was seen to pass through the sky, blazing, sparkling, etc." Twenty-five cents was charged for admission to look at it. The mass is in general quite flat and very irregular, resembling strongly a mass of molten metal thrown on the ground and then pitted. The illustration of the Agram† mass figured by Von Schreibers could be mistaken for the upper side of this were it not that this is larger. It measures $17\frac{1}{2}$ inches (44^{cm}) by $15\frac{1}{2}$ inches

* Affidavits were furnished by the County Clerk and the Mayor of Eureka, as to the trustworthiness of Colonel Betten and Mayor Caraway.

† "Beiträge zur Geschichte und Kenntniss Meteorischer Stein- und Metallmassen," by Dr. Carl von Schreibers, Wien, 1820, folio, plate viii.

(39^{cm}) while the Agram measures 15½ by 12 inches. A high ridge, 5 inches high at the highest point (12·5^{cm}), runs through the center. One half of the mass is not over 3 inches (7·5^{cm}) thick, part of it is only 2 inches (5^{cm}), and around the edge it is only one inch or less. It is only exceeded in size among the irons seen to fall by the Nejed, Central Arabia, now in the British Museum, which fell in the spring of 1865 and weighs 59·420 kilos. The weight is 107½ lbs. (44·213 kilos), and it is intact with the exception of three small points, weighing not more than two ounces in all, which were broken off. One of these is seen in the etched figure, another was sent to Professor Clarke by Colonel Betten to be analyzed, and the third piece was lost.

The two sides are wholly dissimilar. (See Plate XIII.)* In fact, one would scarcely supppse that they belonged to the same mass. The upper side is ridged and deeply dented, while the lower side is flat and covered with shallow, but very large pittings. On top the color is in many places almost tin-white without any coating whatever, and the pittings are very deep and usually quite long, like finger depressions, made in potter's clay. These depressions measure from 2^{cm} to 4^{cm} and from 1^{cm} to 4^{cm}. This side is remarkable for striæ showing the flow and burning and all running from the center toward the edge, identical with those in the Rowton, Nedagolla and Mazapil irons, but on a larger scale. Some of them are thinner than a hair and yet twice as high (like a high knife-edge), and they are from one to four inches long. In one space of 5^{cm} twenty are arranged side by side, and on one small part which is black, there are 50 lines in one inch of space (25^{mm}), all running in the same direction. Near all the pointed edges the fused metal has flowed and cooled so as to hang like falling water. The striæ and marks of flowing are around the edges of the upper surface, (Plate XIII, fig. 1.) On the under side pittings are very shallow but much broader, one depression, apparently made up of four pittings being 20^{cm} long and 9·5^{cm} wide. The whole side is coated with a black crust, 1^{mm} thick and having minute round bead-like markings. On one of the indentations of the lower edge the crust has a strikingly fused appearance as if a flame had been blown on it from the other side. In reality this edge is undoubtedly the place where a greater amount of burning took place when the body was passing through the air. Seven small, bead-like lumps, from 5^{mm} to 10^{mm} in size, which are visible on this side, are drops of metal that were entirely melted and flowed and cooled so that they resemble drops of a thick liquid. There are also to be seen what appear to be cracks, 15 in number and nearly

* The figures on this Plate were made by the Ives process and are faithful reproductions direct from the photograph.

as thin as a hair. One of these is 10^{cm} long and extends from the highly fused edge above mentioned toward the center. The others are from 3^{cm} to 5^{cm} long. These are so evenly arranged that they are without doubt "Reichenbach lamellen" in which the inner troilite has been burnt out. If such is the case they are as abundant as in the Staunton, Va., meteoric iron.

On the upper side ten nodules of troilite are exposed, measuring from 33^{mm} in diameter to 55^{m} long and 25^{mm} wide. On the lower side there are 12 such nodules exposed, 13^{mm} in diameter, while the largest measures 19^{mm} by 39^{mm}. On the upper side these nodules are coated in spots with a black crust similar to that found on the mass, but on the lower side the crust extends completely around the side of the nodules, showing the fusion very plainly. The troilite is very bright and fresh, like a newly broken mineral, and on the upper side one of the nodules shows deep striation, suggesting that the entire nodule is one crystal and the exposed part is only one side of it. In some cases where the nodules were broken they were found to be iridescent. This is one of the octahedral irons showing the Widmanstätten figures beautifully on etching (see

3.

4.

figure 3), and is one of the Caillite groups of Stanislas Meunier and of the *mittlere lamellen* of Brezina. The lamellæ are 1^{mm} wide and the markings more closely approach the Rowton* and Mazapil† irons. Figure 4 shows the etching on the surface of the unpolished exterior, there being no crust. The lower end of the figure which is flat, was produced by the hammering off of the piece: but the etching is really finer where it was done on the natural surface of the iron. The specific gravity of the small piece figured is 7·773. Troilite, as before stated, is very abundant in the mass. Schreibersite and carbon have also been found between the laminæ. Chlorine is present only in slight quantity, as scarcely any deliquescence has been observed.‡

The following is a comparative table of analyses of meteoric irons most nearly approaching this in composition:

* Meteoriten Sammlung des k. k. mineralogisches Hofcabinet in Wien., 8vo, Wien, 1885, Plate 2, figure 2.

† This Journal, III, vol. xxxiii, p. 225, fig. 2.

‡ The full analysis of this iron made by Mr. J. E. Whitfield will be given in an article following this.

	Cabin Creek. (Whitfield.)	Estherville. (Smith.)	Mazapil. (Mackintosh.)	Rowton. (Flight.)	Charlotte. (Smith.)
Iron	91·87	92·00	91·26	91·25	91·15
Nickel	6·60	7·10	7·845	8·582	8·05
Cobalt	trace	0·69	0·653	0·371	0·72
Phosphorus	0·41	0·112	0·30	-----	0·06
C, S, etc.	0·54	99·902	100·038	100·203	99·98
	99·42				

From the fact that the ridged side is so free from crust and the flat side so thickly coated; that the ridged side is covered with striæ and marks of flowing, and the other has so few marks of this kind, and from the fact that at the edges, especially at the indentation the back looks as though a flame had come from the other side—from all these facts the writer concludes that after entering our space the iron traveled with the ridged surface forward (see fig. 1, Plate XIII), the iron burning so rapidly as to be torn off, leaving part of the surface bright. The flame thus passed over the sides, and the indented edge being downward, the flame was driven upward as the iron advanced. The flat side, not being so much exposed, the iron was not so completely consumed, hence a crust and large but shallow pittings. These conditions would perhaps have been entirely different had the mass been round or thicker, for it evidently moved as straight as possible without rotating at all. That it was found in the hole with the flat side down was due perhaps to the fact that having lost its impetus it turned in falling, or, as Professor Newton suggests, it may have been turned by striking the tree, and then have fallen downward almost in a straight line.

As the iron only penetrated to a depth of three feet (90^{cm}) the earth where it struck must have been very compact and the force of the body itself nearly spent. The Agram iron penetrated 14 to 15 feet (425–450^{cm}) in a freshly ploughed field, which shows that in the case of that meteorite there must have been considerable force left, the small mass falling very near it. The Mazapil mass, one tenth of the weight, penetrated only 12 inches (30^{cm}).

I must herewith thank Mayor B. Caraway and Col. J. C. Betten for information furnished me, and Professor F. W. Clarke and Mr. J. E. Whitfield for their courtesy and for the analysis.

ART. L.—*On the Johnson County, Ark., and Allen County, Ky., Meteorites;* by J. EDWARD WHITFIELD.

1. *Johnson County, Ark.*—A fragment of the Johnson County meteorite described in the preceding paper by Mr. Kunz, was received by Professor F. W. Clarke, of the U. S. Geological Survey, from the former owner, Mr. J. C. Betten, of Eureka Springs, Arkansas. This fragment weighed a little more than 35 grams, the exposed surfaces were oxidized, the oxide of iron extending into the numerous cracks, in some cases almost through the specimen. The trace of chlorine found will account in some degree for this oxidation.

The following analysis gives the composition of the iron. The loss is due to the partial oxidation of the iron.

Fe	91·87
Ni	6·60
Co	trace
S	0·05
Combined C	0·15
P	0·41
Mn	trace
Cl	"
Insol. in HCl	0·34
	99·42

Specific gravity = 7·837.

2. *Allen County, Ky.*—This meteorite was found about the middle of June, 1867, by Mr. Jas. H. More, while hoeing tobacco, near Scottsville, Allen Co., Ky. In shape it resembles a wedge, the thickness, at base, being 14^{cm}, width 18^{cm}, and length 16^{cm}; the mass, as found, weighing a little more than 10 kilos and having the characteristic pitted surface. A section shows nodules of troilite, varying in diameter from barely visible points to about 12^{mm}. The markings on an etched surface are exceedingly fine and require the aid of a lens to distinguish them. There appear to be two sets of figures, one of long, very fine lines representing octahedral cleavage, the other series being smaller, more crowded and barely perceptible. An analysis gave the following composition:

Fe	94·32
Ni	5·01
Co	trace
S	0·34
P	0·16
Total C	0·12
	99·95

Specific gravity = 7·848

This iron, as regards markings and general appearance of section, resembles the Scriba and Salt River meteorites more nearly than any others represented in the National Museum collection; but as no complete analyses of these two irons are at hand the chemical comparison cannot well be made. The percentage of iron appears rather high, but duplicate determinations gave corresponding figures.

The material for analysis was received by Professor Clarke from Messrs. Ward and Howell, of Rochester, N. Y., the present owners of the meteorite, to whom we are indebted for the privilege of description.

Chemical Laboratory of U. S. Geological Survey,
Washington, D. C., Feb., 1887.

ART. LI.—*Contributions to Mineralogy;* by W. E. HIDDEN and H. S. WASHINGTON.

THE following pages contain the results of a crystallographic examination of some crystals obtained last summer at the emerald and hiddenite locality in Sharpe's township, Alexander Co., North Carolina. The crystals were nearly all highly polished and brilliant, allowing very exact determinations. The measurements were all made on a Fuess horizontal goniometer with two telescopes. As a rule, the mean of about five of the best results are taken, though in several cases, as in apatite and rutile, the fundamental angles selected were the mean of ten or more determinations.

RUTILE.—The particular crystals examined are of the rarest type of the region and are peculiar to the pockets and veins bearing spodumene. The rare basal plane on the rutile and the predominance of the acute rhombohedron $3R(x30\bar{3}1)$ on the associated quartz crystals are good indications of the gem variety of spodumene in Alexander County. These rutiles are generally quite small, rarely over 3^{mm} thick and 10^{mm} long, but the polish of the planes is extremely good. They are only found as implanted crystals, and, besides the species mentioned above, are commonly associated with brown muscovite, dolomite, siderite, pyrite, and rarely beryl, all well crystallized. The best of these crystals came from pockets in the gneissoid rock about thirty feet below the surface. With one or two exceptions of clear,

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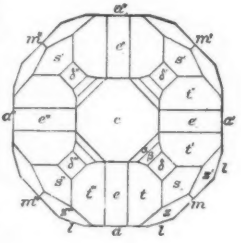


ruby-red crystals, they were of an iron-black color, and brilliant submetallic lustre. They had, usually, the basal pinacoid prominent and well polished; s (111, 1) and e (101, 1-i) were also prominent. The annexed figure shows the most interesting form, observed in two crystals, on which three of the new planes occur. The planes identified were as follows:

Pinacoid, c (001, O), prisms, a (100, i-i), m (110, I), l (310, i-3), dome, e (101, 1-i), pyramids a^*(227, $\frac{2}{7}$), β^*(112, $\frac{1}{2}$) δ^*(223, $\frac{2}{3}$), s (111, 1), π^*(441, 4), t (313, 1-3), z (321, 3-$\frac{3}{2}$) and γ^*(989, 1-$\frac{9}{8}$).

Those marked with an asterisk are new to the species. As a fundamental angle $c \wedge s$ (001 $\wedge$ 111) was taken, giving as a mean of fifteen closely agreeing measurements,

$$c \wedge s\,(001 \wedge 111) = 42° 20' 8''. \quad .\ a : \dot{c} = 1 : 0{\cdot}644252,$$

Miller* giving

$$c \wedge s\,(001 \wedge 111) = 42° 19' 58''. \quad .\ a : \dot{c} = 1 : 0{\cdot}644179.$$

The new planes of the unit pyramidal series were determined by their angles on c (001, O). The agreement between the observed and calculated angles is as follows:

	Calc.	Observed.
$c \wedge a$, 001 $\wedge$ 227	= 14° 35′	14° 36′
$c \wedge \beta$, 001 $\wedge$ 112	= 24° 29½′	24° 30½′
$c \wedge \delta$, 001 $\wedge$ 223	= 31° 16′	31° 14′
$c \wedge \pi$, 001 $\wedge$ 444	= 74° 39′	75° (approx.)

The new plane γ(989, 1-$\frac{9}{8}$) was observed on several crystals replacing the edge s/e (111/101). It furnished the following angles:

	Calc.	Observed.
$s \wedge \gamma$, (111 $\wedge$ 989)	= 2° 42′	2° 57′
$e \wedge \gamma$, (101 $\wedge$ 989)	= 25° 44′	25° 29′

Some of the best observed angles are here tabulated, with the corresponding calculated angles, from the fundamental angles above.

	Calc.	Observed.
$c \wedge s$, 001 $\wedge$ 111	= *42° 20′ 8″	42° 20′ 8″
$c \wedge e$, 001 $\wedge$ 101	= 32° 47½′	32° 47′
$c \wedge t$, 001 $\wedge$ 313	= 34° 11′	34° 8′
$s \wedge e$, 111 $\wedge$ 101	= 28° 26′	28° 26½′
$t \wedge e$, 313 $\wedge$ 101	= 10° 14′	10° 13′
$s \wedge t$, 111 $\wedge$ 313	= 18° 12′	18° 12′
$e \wedge e'$, 101 $\wedge$ 011	= 45° 2′	45° 1′
$e \wedge e''$, 101 $\wedge$ $\bar{1}$01	= 65° 34′	65° 33½′
$e \wedge z$, 101 $\wedge$ 321	= 41° 43½′	41° 42′

Of very exceptional beauty as cabinet specimens were the crystals of rutile found at a depth of forty-three feet in the shaft, just west of the excavation which yielded the crystals above described. The pocket was 10×2×6 feet, and its walls

* Phil. Mag., xvii, 268. 1840.

were covered with beautifully crystallized muscovite, quartz, dolomite, siderite, apatite and rutile. All the contents of this large pocket had a thin chloritic coating, which could easily be removed, in most instances as a very friable shell. The rutile exhibited twinning according to both the known laws, and often both were to be noticed in the same crystal. Crystals with geniculated members of from 1 to 2^{cm} long and 5^{mm} thick were not uncommon, and a few simple crystals were 6^{cm} in length and 1^{cm} in thickness. All were terminated with well polished planes, s(111) and e(101) being dominant. The dolomite as also the siderite crystals showed only the unit rhombohedron and basal pinacoid. These planes were very flat and well polished, no curvature of the planes, as is peculiar to the species, being observed. The rhombohedral face was striated horizontally. Twins of dolomite were common and calcite crystals were observed in parallel position on the rhombohedral face in several instances. One of the dolomites measured nearly 10^{cm} on its edges and was a very exceptional example of the species. In this pocket were found a few apatite crystals of unusual perfection, and these we notice in detail.

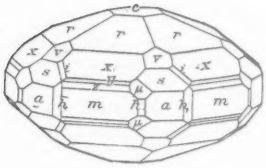
APATITE.—It was plainly evident from their loose attachment and perfection of form that these crystals were the last crystallization of the pocket. For the most part they were rather long, slender prisms, 15 to 25^{mm} by 2 to 4^{mm}, of a pale bluish green color and transparent. A sort of parting parallel to the base was quite noticeable, and the terminations were often highly modified, though, as a rule, only with the more common planes. In one corner of the pocket a small group of muscovite crystals was found which had implanted on them a few very brilliant, wine yellow, transparent, lenticular crystals of apatite. They were of an entirely different habit from the rest of the apatite found, and one of these we have selected for measurement and description. The particular crystal examined was quite small, about 2^{mm} in diameter, and, with the exception of part of one side, where it was attached to the mica by the prism, was almost perfectly developed both above and below. Its habit is almost unique, Schrauf* only figuring one crystal fig. 23, xx) at all similar. The pyramids r (10$\bar{1}$2, $\frac{1}{2}$), x (10$\bar{1}$1, 1), and s (11$\bar{2}$1, 2-2) predominated, while the prisms were nearly absent. Another interesting fact in regard to this crystal is the occurrence of *both* hemihedral prisms h (21$\bar{3}$0) and h_1 (12$\bar{3}$0). The planes observed were as follows:

Basal pinacoid, c (0001, *O*), prisms, m (10$\bar{1}$0, *I*), a (11$\bar{2}$0, i-2), h (21$\bar{3}$0, i-3), h_1(12$\bar{3}$0), pyramids, r (10$\bar{1}$2, $\frac{1}{2}$), x (10$\bar{1}$1), y (20$\bar{2}$1, 2), z (30$\bar{3}$1, 3), v (11$\bar{2}$2, 1-2), s (11$\bar{2}$1, 2-2), dihexagonal pyramids, v (21$\bar{3}$1, 3-$\frac{3}{2}$), i (21$\bar{3}$2, $\frac{3}{2}$-$\frac{3}{2}$) and o (31$\bar{4}$2, 2-$\frac{4}{3}$).

* Atlas der Krystallformen, Plates xviii to xx.

The following figures give a good idea of its habit, though in the perspective figure the prisms are elongated.

2.



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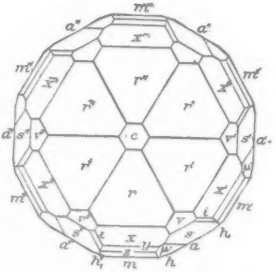


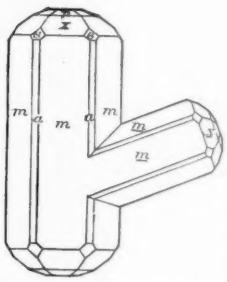
As fundamental angle the following was finally decided upon, it being the mean of about a dozen good determinations.

$x \wedge v$, $(10\bar{1}1 \wedge 11\bar{2}2) = 18° 52'$ giving $a : c = 1 : 0{\cdot}734335$. Kokscharof gives: $a : c = 1 : 0{\cdot}734603$.

The following list of angles may be here inserted:

		Calculated.	Observed.
$c \wedge x$,	$0001 \wedge 10\bar{1}1$	$= 40° 18'$	$40° 15\frac{1}{2}'$
$c \wedge r$,	$0001 \wedge 10\bar{1}2$	$= 22° 58\frac{1}{2}'$	$22° 58\frac{1}{2}'$
$c \wedge y$,	$0001 \wedge 20\bar{2}1$	$= 59° 28\frac{1}{2}'$	$59° 31'$
$c \wedge z$,	$0001 \wedge 30\bar{3}1$	$= 68° 32\frac{1}{2}'$	$68° 36'$
$a \wedge v$,	$11\bar{2}0 \wedge 11\bar{2}2$	$= 53° 42\frac{1}{2}'$	$53° 41\frac{1}{2}'$
$a \wedge s$,	$11\bar{2}0 \wedge 11\bar{2}1$	$= 34° 14'$	$34° 13\frac{1}{2}'$
$r \wedge r'$,	$10\bar{1}2 \wedge 01\bar{1}2$	$= 22° 31'$	$22° 32'$
$y \wedge s$,	$20\bar{2}1 \wedge 11\bar{2}1$	$= 25° 31'$	$25° 35'$
$y \wedge o$,	$20\bar{2}1 \wedge 31\bar{4}2$	$= 12° 45\frac{1}{2}'$	$12° 15'$ (approx.)

4.



z $(30\bar{3}1)$, v $(21\bar{3}1)$, i $(21\bar{3}2)$, o $(31\bar{4}2)$ and h $(21\bar{3}0)$ were small and gave rather poor images, but the other planes were well polished and gave good results.

What is probably a cruciform twin of apatite, from this locality, was also examined. It was composed of two slender, pale bluish green crystals. The figure shows the only occurring planes. One crystal was slightly displaced from the other, but the prisms of both were perfectly parallel. The following measurements were made, giving as a twinning plane s $(11\bar{2}1,\ 2{\cdot}2)$. The first two measurements are the most reliable:

$a^{IV} \wedge a_{IV}$	$= 68° 28'$,	giving	twinning	plane	$\wedge a = 34° 14'$
$s^{IV} \wedge s_{IV}$	$= 68° 51'$,	"	"	"	$\wedge a = 34° 26'$
$m^{V} \wedge m_{I}$	$= 92° 15'$,	"	"	"	$\wedge a = 33° 32'$

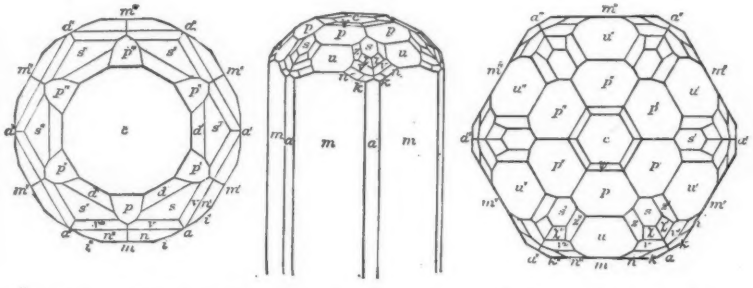
This case is interesting as being the first recorded case of a twin in the species; the agreement between the measured and calculated angles makes it seem improbable that the occurrence is accidental.

BERYL. — Together with crystals of emerald-spodumene (hiddenite) found in one pocket at this same locality was a clear white beryl, about 1cm by ·7cm. This was also examined, and a basal projection is given in figure 5. It shows the rather rare plane d ($33\bar{6}4$, $\frac{3}{2}2$), which gave the following angle: $c \wedge d$, $0001 \wedge 33\bar{6}4$ = calc., 36° 48′, = observ., 37° 7′ approx.

On another larger, clear white beryl, a plane which is approximately represented by the symbol φ ($8{\cdot}7{\cdot}\bar{1}5{\cdot}6$, $\frac{5}{2}{\cdot}{-}\frac{1}{8}\frac{5}{8}$) was observed in the zone $s \wedge p'$ ($11\bar{2}1 \wedge 12\bar{3}0$). It was determined by the following angles:

	Calc.	Observed.
$s \wedge \phi$, $11\bar{2}1 \wedge 8{\cdot}7{\cdot}\bar{1}5{\cdot}6$	39° 31′	39° 20′ (approx.)
$v \wedge \phi$, $12\bar{3}1 \wedge 8{\cdot}7{\cdot}\bar{1}5{\cdot}6$	8° 45′	9° (approx.)

On the same crystal a plane was observed replacing the edge s/a ($11\bar{2}1/11\bar{2}0$). It has approximately the symbol Ψ $8{\cdot}7{\cdot}16{\cdot}8$, $2{\cdot}1\frac{6}{7}$. It was determined by the following angle: $c \wedge \Psi$ ($0001 \wedge 8{\cdot}7{\cdot}16{\cdot}8$) = 48° 45′ calc., 48° 46′ observed.



It is noteworthy that the highly modified beryls of this region only occur rarely and when associated with spodumene or albite. Another interesting feature is that white or very pale greenish beryls are found with the deepest green spodumene. It has before been noted that the quartz and beryl of Alexander Co. are more highly modified when they are implanted on the feldspathic layers of the walls of the pockets. Two emerald beryls were examined which were found in 1881, at a depth of 34 feet, in a little pocket whose walls were almost wholly covered with crystals of albite twinned parallel to the base. Only four emeralds were found, and they averaged about 1cm in the three dimensions. The

pocket was free from all decomposition whatever. The crystals were of good color, transparent, and had the commoner planes well polished. They differed to some extent in habit, and figures 6 and 7 show the occurring planes on two of them, though the berylloids are much exaggerated, and the basal pinacoid reduced in size.

The occurring planes were as follows:

c (0001, O), m (10$\bar{1}$0, I), a (11$\bar{2}$0, i-2), i (21$\bar{3}$0, i-$\frac{3}{2}$), s (11$\bar{2}$1, 2-2), ψ^* (1·0·$\bar{1}$·12, $\frac{1}{12}$), p (10$\bar{1}$1, 1), u (20$\bar{2}$1, 2), n (31$\bar{4}$1, 4-$\frac{4}{3}$), v (31$\bar{2}$1, 3-$\frac{3}{2}$), χ^*(8·7·$\bar{1}$·5·7, $\frac{1}{7}$·$\frac{1}{8}$), k (42$\bar{6}$1, 6-$\frac{3}{2}$), z (42$\bar{6}$3, 2-$\frac{3}{2}$).

The plane (8·7·$\bar{1}$·5·7) was rounded somewhat, as was the case with (5·4·9·4) observed by vom Rath. This plane, new to the species, and whose symbol can be regarded as only approximately determined, gave the following angles:

	Calculated.	Observed.
$\chi \wedge \chi'$, 8·7·$\bar{1}$·5·7 $\wedge$ 7·8·$\bar{1}$·5·7	= 3° 17′	3° 50′ (approx.)
$s \wedge \chi$, 11$\bar{2}$1 $\wedge$ 8·7·$\bar{1}$·5·7	= 2° 33′	2° 50′ "

The new pyramid of the first series was determined as follows:

$c \wedge \psi$, 0001 $\wedge$ 1·0·$\bar{1}$·12 = 2° 45′ calc. 2° 52′ observed.

A list of the angles observed with the corresponding ones calculated from Kokscharof's measurements is here given:

	Calculated.	Observed.
$c \wedge p$, 0001 $\wedge$ 10$\bar{1}$1	= 29° 56½′	29° 56′
$c \wedge u$, 0001 $\wedge$ 20$\bar{2}$1	= 49° 2½′	49° 6′
$c \wedge s$, 0001 $\wedge$ 11$\bar{2}$1	= 44° 56′	44° 52′
$m \wedge s$, 10$\bar{1}$0 $\wedge$ 11$\bar{2}$1	= 52° 11′	52° 7′
$m \wedge v$, 10$\bar{1}$0 $\wedge$ 21$\bar{3}$1	= 37° 42½′	37° 39′
$m \wedge n$, 10$\bar{1}$0 $\wedge$ 31$\bar{4}$1	= 28° 54½′	28° 55′
$a \wedge k$, 11$\bar{2}$0 $\wedge$ 42$\bar{6}$1	= 21° 5′	21° 4′

It was a noteworthy fact that on all these beryls the prism m (10$\bar{1}$0) was perfectly smooth, while the prism a (11$\bar{2}$0) was etched over the whole surface with shallow isosceles-triangular pits, apex up and broader than high.

TOURMALINE.—Some well polished black crystals were found implanted in cavities. They gave such excellent measurements that the comparison of the results obtained from them with those of Des Cloizeaux is not without interest.

		H. S. W.	Des Cloizeaux.
$a : c = 1 : 0{\cdot}89905$			
$-\frac{1}{2}R \wedge -\frac{1}{2}R\,\vartheta$	(10$\bar{1}$2 $\wedge$ $\bar{1}$102)	= 47° 1′ 45″	46° 52′
$-\frac{1}{2}R \wedge \frac{1}{2}R$	(10$\bar{1}$2 $\wedge$ 01$\bar{1}$4)	= 23° 30′	23° 26′
$O \wedge R$	(0001 $\wedge$ 01$\bar{1}$1)	= 46° 4′	45° 57′
$R \wedge R$	(01$\bar{1}$1 $\wedge$ $\bar{1}$011)	= 77° 11′	76° 59′
$R \wedge -\frac{1}{2}R$	(01$\bar{1}$1 $\wedge$ 10$\bar{1}$2)	= 38° 35′	38° 29½′

The largest crystal was only 6^{cm} long by 12^{mm} thick. Some few were noticed to be hemimorphic in the terminal planes.

The basal pinacoid was rare, $-\frac{1}{2}R$, $\frac{1}{4}R$ and R predominated. One crystal was terminated almost wholly by $\frac{1}{4}R$.

QUARTZ.—Vom Rath has already called attention to the occurrence of the plane $k_2 = (4\bar{1}\bar{3}0)$ i-$\frac{4}{3}$ on quartz crystals from Alexander County, North Carolina.* Its best development seems to have been found on crystals from the gem mine, in Sharpe's township. Thus far this plane has been described as "a hemihedral twelve-sided prism," and its fine vertical striation and often observed right-angled intersection with the trapezohedron 4-$\frac{4}{3}$ $(4\bar{1}\bar{3}1)$ at once characterized it and made it easily recognized. Quite recently we have obtained several crystals, from this same locality, which apparently presented this plane *holohedral*, in pairs on each consecutive prismatic edge, instead of on alternate edges as before noted.

Vom Rath's measurements gave as the angle of $k_2 \wedge g\,(I)$ 13° 52′ (calculated 13° 54′), while we found $k_2 \wedge k_2$ adjoining = 31° (calculated 32° 12′). One of the new crystals ($8 \times 4\frac{1}{2}^{cm}$) exhibited this rare plane 13^{mm} wide and 19^{mm} long.

We add also to this paper notices of a new plane on topaz and a twin of corundum.

TOPAZ.—This was a clear white crystal of about 1×2^{cm}, which was sent to us from the noted locality near Zacatecas, Mexico, where they are found in the detritus of trachyte very similar to the occurrences in Utah described by Alling† and in Colorado by Cross. This crystal had the usual habit of topazes from Durango. Replacing the solid angle formed by 110, $1\bar{1}0$, and 201, there was observed a new plane which has the symbol (701, 7-i). A comparison of its observed and calculated angles is here given:

	Calculated.	Observed.
001 ∧ 701	80° 58′	81° 6′
110 ∧ 701	8° 29¼′	8° 31′

CORUNDUM.—A twin of corundum was found among a lot of gem material received from Ceylon. Its high polish and twinned form are features rarely observed in the species. It was of a clear grayish blue color. Both basal pinacoids were present and were highly polished. The angle observed between the two was 114° 20′, giving as a twinning plane the unit rhombohedron.

* Sitzungsberichte der Niederrhein. Gesellsch. f. Nat.-u. Heilkunde, 6 July, 1885. Zeitschrift für Krystallographie, etc. xii, 456.

† This Journal, III, xxx, 146, 1887.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *On the decomposition of Potassium chlorate by heat.*—At the suggestion of Thorpe, Frankland (P. F.) and Dingwall have studied the decomposition which potassium chlorate undergoes when heated, extending their observations also to the perchlorate. In the first series of experiments, the chlorate was heated over a naked flame, different quantities of oxygen being driven off in each experiment and determined by loss of weight. The chloride formed, as well as the chlorate remaining, were also determined. In the first two experiments, 2·66 and 5·19 per cent of oxygen (calculated on the weight of $KClO_3$ taken) were evolved respectively. And the decomposition proceeded according to the equation $(KClO_3)_5=(KClO_4)_5+(KCl)_3+(O_2)_2$. In the third, in which 6·47 per cent of oxygen was evolved, the reaction was intermediate in its results between the above equation and $(KClO_3)_{10}=(KClO_4)_6+(KCl)_4+(O_2)_3$. Since there was no guarantee in these experiments that the reaction was not complicated by the decomposition of the perchlorate at first formed, the authors made a second series of experiments, selecting as the temperature that of boiling sulphur, since at this temperature the perchlorate is not decomposed. The decomposition was at first active, but soon became sluggish. In one experiment 5·3345 grams of chlorate exposed in the sulphur bath for 98 hours, lost 116·6 milligrams during the first five hours, and only 8 milligrams during the last. In the first two experiments, in which 6·89 and 6·78 per cent of oxygen were respectively evolved, the reaction took place nearly in accordance with the second of the above reactions. In the third experiment, powdered glass was mixed with the chlorate; and then the decomposition was almost complete, 14·3 per cent of oxygen being evolved, nearly according to the formula $(KClO_3)_2=KClO_4+KCl+O_2$. Hence the decomposition of potassium chlorate by heat more nearly approaches the equation $(KClO_3)_2=KClO_4+KCl+O_2$ in proportion as this decomposition is more complete. In experimenting with perchlorate, definite portions were heated over a naked flame in a piece of combustion tube sealed at one end and loosely plugged with glass-wool at the other, a different proportion of oxygen being liberated in each experiment. In the residue the proportion of chloride to chlorate was determined. The results when tabulated form a continuous series; the proportion of chlorate formed diminishes as the oxygen evolved increases, while the chloride produced increases. When the oxygen set free was 8·77 per cent, the chlorate formed was 24·85 per cent of the perchlorate employed; but when 36·81 per cent of oxygen was evolved, the chlorate was only 5·27 per cent. Heating the perchlorate in sulphur vapor, when previously mixed with MnO_2, resulted in a complete decom-

position according to the equation $KClO_4 = KCl + (O_2)_2$. To demonstrate beyond question this formation of chlorate, the perchlorate was heated until it lost about 10 per cent of its weight, then dissolved in water and fractionally crystallized. The third fraction contained 41·68 and the fourth 42·91 per cent of chlorate. —*J. Chem. Soc.*, li, 274, March, 1887. G. F. B.

2. *On the Influence of Silicon on the Properties of Iron and Steel.*—TURNER has made experiments at the South Staffordshire Steel and Ingot Iron Company's works at Bilston, to determine the influence which silicon exerts upon the properties of iron and steel. A small, modified Deville furnace was erected on the platform between two Bessemer vessels. The crucibles used were of Stourbridge fire clay, and were capable of holding about 35 pounds of steel. After the necessary annealing the pot was placed in the furnace and raised to about the melting point of cast iron. A few minutes before the mixture was to be made, a weighed quantity of silicon pig was introduced into the crucible and the temperature was increased by turning on more blast. At the right moment the crucible was rapidly removed from the furnace and brought to the mouth of the converter, while at the same time a ladle of metal was drawn from the vessel. This was poured into the crucible and the metal well stirred by means of a rod of basic steel. After cooling, the crucible was broken and the ingot numbered. Each ingot was submitted to mechanical tests and was carefully analyzed. The author concludes that on adding silicon in the form of silicon pig to the purest Bessemer iron, the metal is quiet in the mould even when only a few hundredths per cent of silicon is added. The metal is originally red-short, especially at a dull red heat, though it works well at a welding temperature; the red-shortness being increased by silicon. In all cases examined the metal was tough cold and welded well, the silicon having little or no influence. Silicon increases the elastic limit and tensile strength, but diminishes the elongation and the contraction of area, a few hundredths per cent having a remarkable influence in this respect. The appearance on fracture by tensile force, is changed from finely silky to crystalline, while the fracture produced by a blow gradually becomes more like that of tool steel as the silicon increases. The hardness increases with increase of silicon, but appears to be closely connected with the tenacity. With 0·4 per cent of silicon and 0·2 per cent of carbon, a steel was obtained difficult to work at high temperatures, but tough when cold, capable of being hardened in water, and giving a cutting edge which successfully resisted considerable hard usage.—*J. Chem. Soc.*, li, 129, February, 1887. G. F. B.

3. *Agriculture in some of its relations with Chemistry;* by F. H. STORER, S.B. A.M., Prof. Agric. Chem. Harvard University. Two volumes, 530 and 510 pp., 8vo. New York, 1887 (Scribner's Sons).—This work, by the able Professor of Agricultural Chemistry in Harvard University, is a contribution, of

high scientific value, on practical agriculture. The author understands his subject through all the wide range of requirements, and largely as the result of personal investigation and experimental trials. He commences with the relations of soil and air to the plant, treats of the atmosphere as a source of plant food, of movements of water in the soil, of tillage, of the wide subject of manures or fertilizers, as to kinds, preparation, effects, conditions of use, materials in the soil, nearly 500 pages being devoted to these and related topics; also of the rotation of crops, the character and needs of various kinds of farms, farming and crops. The work is, hence, one for the practical farmer, the landscape gardener and the student of scientific agriculture, and also for the large class not farmers who like to know what is going on in their cultivated grounds, and what are the best methods of improvement. Professor Storer's Preface gives high praise to the work and works of Professor S. W. Johnson, of New Haven; and the opinion expressed we know to be fully reciprocated by the agricultural department at Yale, with reference to the labors of Professor Storer of Harvard.

4. *Studies from the Laboratory of Physiological Chemistry, Sheffield Scientific School of Yale University, for the year* 1885–86. Edited by Professor R. H. CHITTENDEN, Ph.D. Volume II, 236 pp. 8vo. New Haven, 1887. (From the Transactions of the Connecticut Academy, vol. vii.)—This volume, like its predecessor, noticed in the Journal for August, 1886, bears witness to the unusual degree of activity in original research in Professor Chittenden's laboratory. The papers contained in it are ten in number. The first, on globulin and globulose bodies, and the second, on peptones (republished from the Zeitschrift für Biologie) are by Professors Kühne (Heidelberg) and Chittenden, and form a continuation of previous work by the same authors upon albumose bodies, and at the same time are a commencement of a study of the various primary cleavage products formed by the action of pepsin from the purer albumins. The other papers are upon a variety of more or less closely related topics, the dehydration of glucose in the stomach and intestines, by Professor Chittenden; on the influence of uranium salts on the amylolytic action of saliva, and the proteolytic action of pepsin and trypsin, by Professor Chittenden and M. T. Hutchinson; the relative distribution of antimony in the organs and tissues of the body, also on the influence of antimonious oxide on metabolism, by Professor Chittenden and Joseph A. Blake, and a number of others. It has not often been possible for a laboratory to give to the world within a short period so important a series of contributions as are contained in these two volumes.

II. GEOLOGY AND NATURAL HISTORY.

1. *To all American Geologists.*—At a meeting of the American Committee (elected by the Standing Committee of the

American Association for the Advancement of Science to represent American Geology in the International Congress of Geologists) held in Albany on April 6, there were present, Professor James Hall (President), Professors Hitchcock, Stevenson, Williams, Winchell, Cook, Cope and Frazer (Secretary). Professors Emerson and Smock, Clarke, Dr. Rominger and Mr. Beecher were invited to be present at the sessions of the Committee. By unanimous vote Mr. W. J. McGee was invited to take the place of Major Powell, who was prevented by sickness from attending.

The Secretary announced that there had been forty-five subscribers for fifty copies of the geological map of Europe.

A motion was adopted abolishing the Committee of the Whole and its officers, and entrusting the duty of preparing reports on the separate divisions of the geological column, to eight Reporters, who were thereupon unanimously elected (see card to Geologists below).

The following was adopted by the Committe: *Resolved*, That we recommend to American geologists the acceptance of the conclusions of the International Congress, said changes to be formulated at a subsequent meeting of the Committee; and it being understood that the Committee will present such additions as are deemed necessary by American geologists, to the Congress of London in 1888.

2. *International Congress of Geologists — American Committee.* Philadelphia, April 22, 1887.—At the recent meeting of the American Committee in Albany, "Reporters" were elected, whose duty is to prepare reports on the several parts into which, for convenience, the geological column has been divided. The assignment is as follows: Quaternary, Recent, Archæology, Major Powell, D'r U. S. G. S., Washington, D. C.; Cainozoic (Marine), Professor E. A. Smith, State Geol. Univ. Ala., Tuscaloosa; Cainozoic (Interior), Professor E. D. Cope, 2102 Pine St., Philadelphia; (Mesozoic), Professor Geo. H. Cook, State Geol. Rutgers Coll., New Brunswick, N. J.; Upper Palæozoic; Carbonic, Professor J. J. Stevenson, Univ. City of New York, N. Y.; Devonic, Professor H. S. Williams, Cornell Univ., Ithaca, N. Y.; Lower Palæozoic, Professor N. H. Winchell, St. Geol. Univ. of Minn., Minneapolis; Archæan, Dr. Persifor Frazer, 201 South 5th st., Philadelphia, Pa.

It is the duty of these Reporters to obtain, each for his own subject, as complete information as possible from American geologists interested in it; but on account of the difficulty of ascertaining the names of all who have information to impart on a particular topic, it will not be possible to address letters to more than a few of those who are known to have studied a subject. For this reason each of the undersigned appeals to *all* his professional brethren for aid in preparing the report which is entrusted to him. It is not possible that any single scheme will be approved by all geologists, and therefore it is the more necessary that there should be a fair statement of any opposing

views in each report. These reports will be submitted to criticism and discussion at the next meeting of the American Committee, to be held, probably, next August, and an effort is being made to have them discussed formally in Section E at the meeting of the American Association for the Advancement of Science, to be held afterwards. With such advantages for knowing the views of our countrymen, there seems every prospect that the American representation at the next Congress will exercise an influence proportional to the importance of its constituency.

Geologists who have convictions as to classification, nomenclature, coloration or any of the numerous subjects brought before the last Congress (which are similar to those to be brought before the next), or who believe that the Congress has erred in any of its recommendations, or who have original observations or deductions bearing upon any part of the seven subjects above assigned to Reporters, are earnestly requested to communicate their views as soon as possible to the Reporter having in charge the subject to which they relate. Those who neglect to do this cannot justly complain if their peculiar views are neglected in the reports.

GEORGE H. COOK, J. J. STEVENSON, H. S. WILLIAMS, PERSIFOR FRAZER, N. H. WINCHELL, E. D. COPE, EUGENE A. SMITH, *Reporters.—Communicated by the Secretary, Dr. Frazer.*

3. *A Marine Biological Laboratory.*—The great importance of a Marine Biological Laboratory at some point on the New England coast for instruction and investigation has led to the selection of a board of Trustees for the management of such a laboratory, consisting of Prof. Wm. G. Farlow, Miss Florence M. Cushing, Prof. A. Hyatt, Dr. C. Minot, Miss S. Minns, Prof. Wm. T. Sedgwick, and also of a committee for the raising of the necessary funds and construction and arrangement of the laboratory, of which Prof. Hyatt is chairman. The laboratory, which has been in successful operation since 1881, at Annisquam, will be merged in the new institution. The special location has not yet been designated. The circular which has been issued states that the estimated cost of location, building and equipment is seven thousand five hundred dollars; and a like amount for carrying on the work for five years. The committee therefore desire to raise the sum of fifteen thousand dollars and request subscriptions for that purpose from all those who are interested in improving the methods of education and contributing to the advancement of science. Subscriptions may be sent to Samuel Wells, Esq., 31 Pemberton Square, Boston, Mass. There ought to be no difficulty in raising twice this sum.

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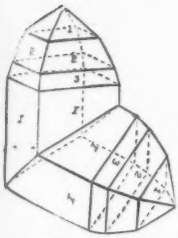

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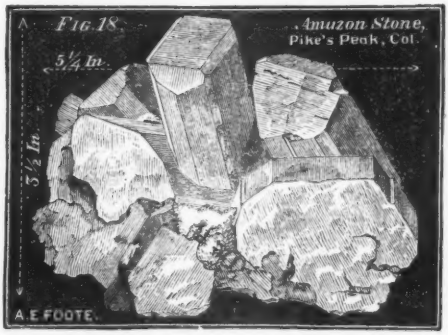

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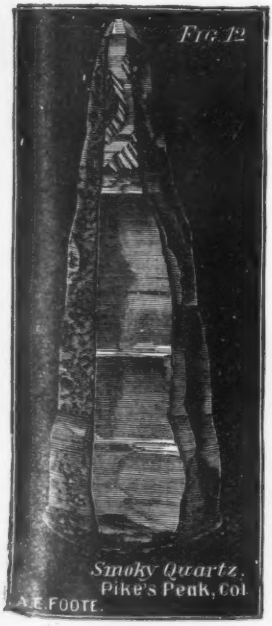

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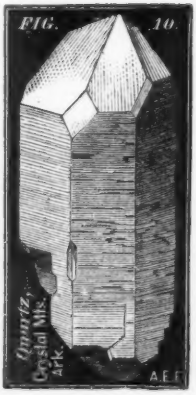

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